THE ECONOMICS OF PETROLEUM

BY

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TO

Grace Needham Pogue

PREFACE

The purpose of this book is to present, in perspective, the more important economic facts relating to petroleum; to interpret the changes that are rapidly taking place in this field; and to project the trend of these changes into the immediate future. The book is designed to be of service to the business man, the engineer, and the practical worker, not only in the petroleum industry, but in those industrial fields dependent upon the products of petroleum as well.

While the activities dependent upon petroleum are indispensable, the reserves of this substance are limited in size. And the rate at which the supply may be brought to the surface is falling behind the rate at which the demand for oil is growing. These conditions have already called for large imports from Mexico. More recently, they have directed the attention of the United States toward other foreign supplies to supplement the domestic output. In the years ahead, they may be expected to bring on far-reaching changes in the technology and economic structure of the petroleum industry, changes which may even go so far as to influence strongly the interrelated industrial fields dependent upon petroleum. Many of these changes, in fact, have already registered their initial effects during the past five years.

Irrespective of the quantity of recoverable petroleum underground, the output of this country must inevitably decline. This decline, however, may be expected to be a slow recession over a considerable number of years, rather than a sharp and sudden curtailment. The peak of production was possibly reached in June of 1921. That this record will be substantially bettered is unlikely, although it can doubtless be surpassed if the price of crude petroleum advances sufficiently. But whether the output of petroleum in the United States has actually or almost reached its maximum rate is immaterial. Likewise, the exact size of the unmined reserve is of secondary importance. The point to be emphasized is the coming necessity for increasing the over-all efficiency of petroleum—a problem that concerns not only the producers and refiners of oil but the manu-

facturers of appliances that consume its products, as well. From now on the tendency will be to use relatively less of the material itself, but to put greater effort into increasing the service value extracted from it.

In the pages following, some departures have been made from the usual methods of presentation. The statistics, for the most part, are given in large units—an expedient that greatly simplifies their presentation and utilization, without any sacrifice of their significance. In general, the unit has been so chosen that the data could be expressed by three digits, with a decimal point if necessary, the third digit being raised one if the fourth digit in the original listing was 5 or over. Special emphasis is placed upon graphic analysis of the statistical data, and a number of relatively new types of charts have been introduced. The ratio chart, in particular, has been extensively employed. The graphic presentation has been so developed that the reader may gain a perspective of the petroleum industry from a study of the charts alone, without recourse to the text. The percentages and index numbers were calculated by means of a 10-inch slide rule and are precise within the limits of that instrument. The statistical tables have been doubly checked from the original data and it is to be hoped are reasonably free from errors.

In the preparation of this book, the writer has been aided by information published, or especially provided, by many organizations. He is particularly indebted to the following: American Gas Association; American Petroleum Institute; Automotive Industries; Federal Trade Commission; National Automobile Chamber of Commerce; National Petroleum News; Oil and Gas Journal; Oil, Paint, and Drug Reporter; Sinclair Consolidated Oil Corporation; Smithsonian Institution; Society of Automotive Engineers; Society of Western Engineers; Standard Oil Company (New Jersey); Tide Water Oil Company; U. S. Bureau of Foreign and Domestic Commerce; U. S. Bureau of Mines; U. S. Fuel Administration; U. S. Geological Survey; U. S. National Museum.

A large number of individuals have contributed to this undertaking in a substantial manner. Many acknowledgments are made throughout the text. In addition, the writer wishes to express his cordial appreciation to: Ralph Arnold, Mowry Bates, Philip Brasher, E. J. Buchaca, F. G. Clapp, Northrop Clarey, Thomas Cox, E. W. Dean, E. De Golyer, J. A. Doyle, M. C. Ehlen, L. M. Fanning, V. R. Garfias, Chester G. Gilbert, George B. Gifford, Robert B. Harper, Frank Howard, Arthur D. Little, Isador Lubin, Van H. Manning, H. F. Mason, R. S. McBride, Chester Naramore, C. C. Osbon, W. F. Parish, Raymond Prescott, M. L. Requa, George E.

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The writer is fully aware of the difficulties of the task which he has attempted to perform, and he will welcome constructive criticisms from any source. He offers no apology for the projection of present trends into the future. *"The prime function of a science is to enable us to anticipate the future in the field with which it has to deal."*

JOSEPH E. POGUE.

NEW YORK CITY,
Sept. 15, 1921.

CONTENTS

ECONOMICS OF PETROLEUM

CHAPTER I

THE ECONOMIC ORGANIZATION OF THE PETROLEUM INDUSTRY

The petroleum industry is distinguished among industrial activities in its form as a nearly self-contained economic entity embracing the four related functions of production, transportation, manufacturing and marketing. The economic organization of the petroleum industry, as differentiated from its financial structure, is shown graphically in Fig. 1.

The production of petroleum has to do with the discovery, development, and exploitation of oil-bearing territory. It involves the incidental output of considerable quantities of natural gas, a source of supplementary revenue and productive of some gasoline which is blended with the ordinary supply of refinery gasoline. The production of crude petroleum deals with a wasting asset, a mobile and illusive substance, a product subject to rapid and sensational development; and takes on in consequence a unique and specialized character which sets it distinctly apart from industrial activities in general. As time goes on, the field of petroleum production may be expected to enlarge its scope and include the manufacture of oil from volatile coals and oil-shale.

The transportation of crude petroleum, faced with the problem of moving a bulky liquid raw material, has grown along individual lines, with the development of pipe-lines and tank-steamers to facilitate the efficient movement of this substance. Petroleum is handled in almost entire independence of the usual agencies of transport.

The refining of crude petroleum is a manufacturing enterprise involving the principles of chemical control and multiple production. Through the agency of pipe-line and tanker transportation, the substantial portion of the refining activity has been enabled to grow up in locations readily accessible to the markets for petroleum products.

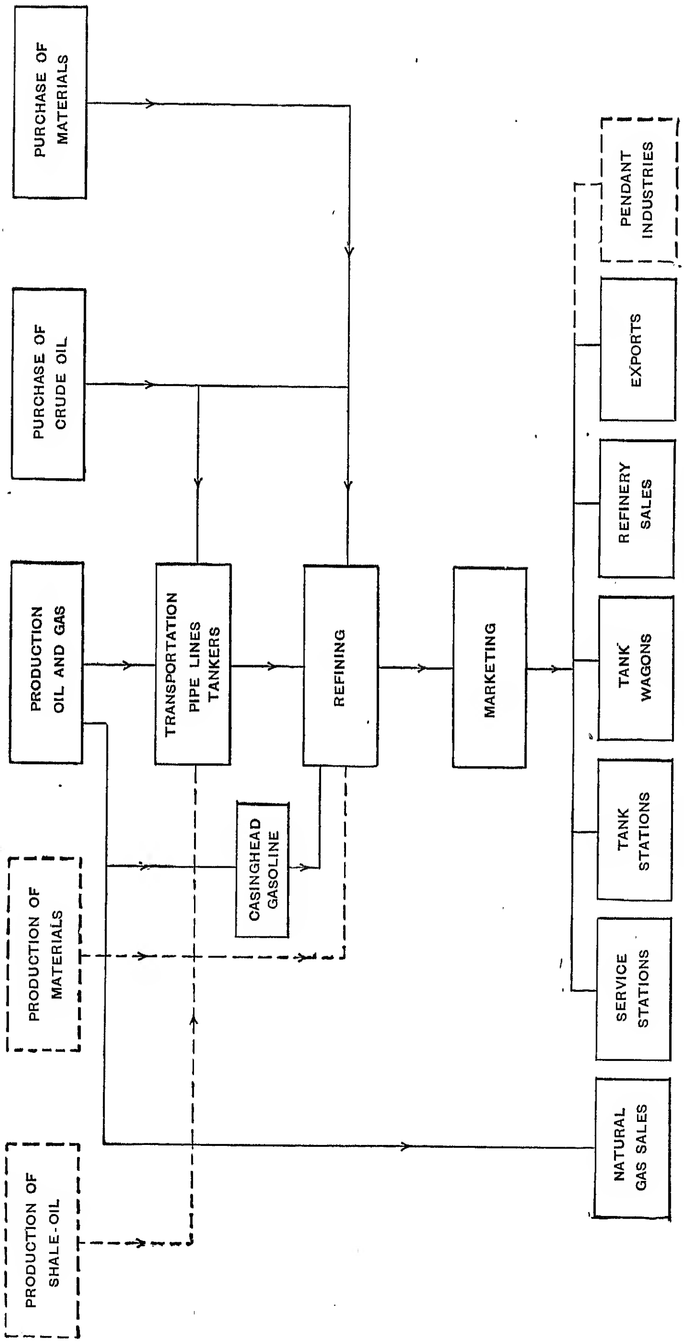


FIG. 1.—Economic organization of the oil industry.

The marketing of petroleum products has been carried on largely by the refining interests, and in order to maintain an outlet for an ever-increasing flow of these materials, this phase of the industry has been extensively cultivated and highly perfected.

The rapid exploitation of the petroleum resource has led to the attainment of a notable degree of competence in transportation and distribution, but, in the presence of an abundance of raw material, production and refining for the most part have developed in a wasteful and improvident manner. Conditions ahead, however, may be expected to bring a growing measure of efficiency into the realms of production and refining.

Integration of the Industry.—In a fundamental economic sense, the petroleum industry is highly integrated and an activity that would be expected from a purely physical standpoint, to function with maximum efficiency as a natural monopoly. The tendency toward financial integration in keeping with the underlying economic structure was effectively displayed during the earlier decades of the development, culminating in a country-wide business organization, the Standard Oil Company of New Jersey. The drift toward financial integration, however, met the opposition of public economic policy, and in 1911 the Standard Oil Company was financially disintegrated by a judgment of the Supreme Court.

At the present time, the petroleum industry is composed of the original units of the Standard Oil Company of New Jersey, operating throughout the United States without financial collusion though with a certain degree of economic consistency arising from the fundamental economic integration which could not be destroyed by legal pronouncement; and of a larger number of other dissociated units, including roughly about half of the entire industry. The companies originally comprising the Standard Oil Company of New Jersey are commonly referred to as the Standard companies, or Standard group; while all other companies are spoken of as the Independents, or Independent group.

Viewed from another angle, the petroleum industry is composed of large units representing corporate enterprises with extensive aggregates of capital, and small units of more restricted resources and scope. The large units include companies which produce, transport, refine, and market, as well as those which undertake a less complete range of activities. The small units usually operate in only one of the four major divisions. In 1919 according to the Federal Trade Commission,[1] 21.3 per cent of the crude petroleum output of the United

[1] Summary of the report of the Federal Trade Commission on the Pacific Coast Petroleum Industry, April 7, 1921.

States was produced by nine Standard companies; 38.1 per cent by large independent companies of over 1 million barrels output; and 40.6 per cent by smaller companies and companies not reporting to the Commission. Of the total production of the large companies, 25.6 per cent was credited to companies engaged in production solely; and 74.4 per cent, to companies which also operated refineries. In regard to the crude petroleum refined in 1919, companies belonging to the Standard Oil group handled 43.8 per cent; large independent companies, 41.1 per cent; and companies not reporting to the Federal Trade Commission, 20.2 per cent. Figures covering 84 per cent of the refinery consumption of the country in 1919 show that 38.3 per cent of the crude run to stills was produced by the refining companies or affiliated interests. Of the trunk pipe-line mileage, approximately 69 per cent in 1920 was in the hands of the Standard companies and practically all of the remainder belonged to large independent interests.

Size of the Industry.—The magnitude of the petroleum industry is difficult to convey accurately in statistical terms. Table 1 gives a number of measurements, some amounting merely to rough estimates, drawn from a variety of sources.

TABLE 1.—THE MAGNITUDE OF THE AMERICAN PETROLEUM INDUSTRY

No. of producers of crude petroleum, Jan. 1, 1921	4,048
No. of producing oil-wells, Oct. 31, 1920	258,600
Production of crude petroleum, 1920	443 million barrels
Imports of crude petroleum, 1920	105 " "
Pipe-line companies, 1920	91
No. miles of pipe-lines, 1920	45,500
Tonnage of tank-steamers, Jan. 1, 1921	5,215,961
No. of refineries, Jan. 1, 1921	415
Daily capacity of refineries, Jan. 1, 1921	1,888,000 barrels
No. of manufacturers of natural-gas gasoline, 1921	432
Output of petroleum products, 1920	20 billion gallons
No. of compounders, marketers, and jobbers, 1920	1,578
No. of tank-cars in operation, Jan. 1, 1921	137,000*
Estimated value of petroleum products sold in 1920	3 billion dollars
Manufacturers and dealers in oil equipment	658
Estimated investment in American petroleum industry	6 billion dollars

* Includes tank-cars of all kinds in United States and Canada.

It is apparent that the petroleum industry is one of the major industrial activities of the country. Moreover, it represents the fuel support of automotive transportation and supplies the lubricants essential to the operation of all industrial activities, and hence underwrites the progress of modern civilization. The total wealth of the country, including real estate, railroads, mines, public utilities, and so on, is estimated to be in excess of 200 billion dollars, which indicates that the estimated investment represented by the petroleum industry runs close to 3 per cent of the country's total wealth.

Investment in the Industry.—A rough appraisal of the investment in the American petroleum industry has been made by Ross,[1] and the figures thus calculated are shown in Table 2. It should be borne in mind that the figures are approximations and useful merely as indications of the magnitude of the industry as measured in financial terms.

TABLE 2.—ESTIMATE OF THE INVESTMENT IN THE AMERICAN PETROLEUM INDUSTRY IN 1920 (After Ross)

Items	Millions of Dollars
Production	3542
Pipe-lines	400
Tankers	250
Refineries	1795
Marketing equipment	660
Crude inventories	394
Refined inventories	370
Total	7411

The estimate of production represents the present value of future production, as based on the barrel-day theory of valuing oil properties. According to this method, the settled daily production is multiplied by an arbitrary number of dollars called the barrel-day price, which is usually the prevailing price times one thousand. Needless to state, such a method when applied to the whole country yields a highly generalized result. This method of valuation takes no account of increases in value due to come in respect to a depleting resource, although such increments will tend to be offset by increasing production costs, and by the time element involved in a

[1] See Victor Ross, The Evolution of the Oil Industry, 1920, pp. 153–159.

slowing output after the maximum rate is attained. The present value of future production represents an investment of the petroleum industry in a qualified sense only, since upwards of 90 per cent of the oil acreage in the United States is leased from private owners.

The actual investment in the crude petroleum business may also be estimated on the basis of figures published by the Federal Trade Commission, showing that the capital stock, surplus, and funded debt of 82 companies producing 62 million barrels of crude petroleum in 1919 was 366 million dollars, or 5.9 dollars per barrel of annual output. If this ratio is applied to the total 1919 production of 378 million barrels, the total estimated investment in the crude petroleum business would become about 2200 million dollars.

The pipe-line system of the country is estimated by Ross to have a 1920 replacement value of 400 million dollars, although representing an actual estimated investment of 300 million dollars. The U. S. Bureau of Mines, however, has estimated the pipe-line investment on the basis of the actual cost of the property to be approximately 500 million dollars.

The refineries of the country, including wharves, railroad terminals, cooperage plants, tin container plants, foundries, machine shops, etc., are estimated by Ross to represent in 1920 a total investment of 1795 million dollars. On the basis of reports from 138 petroleum-refining companies in 1919 running 84 per cent of the total refinery consumption of the country, whose investment was given by the Federal Trade Commission as 2088 million dollars, the total investment of the entire petroleum refining industry would amount to about 2480 million dollars.

The investment represented by the American fleet of oil-tankers is placed by Ross at 250 million dollars for 1920. The original cost of the tankers completed by early 1921 will run higher than this total, since much of the tonnage was built at the height of cost.

The inventories of crude petroleum and refined products, as given by Ross for April, 1920, are appraised by multiplying the quantities on hand at that time by the current market price.

The investment of 660 million dollars represented by the marketing equipment, as shown in Table 2, is calculated on the basis of 4 dollars per barrel for the real estate and equipment engaged in retail marketing and 1 dollar a barrel for tanks and docks employed in fuel-oil sales. Included under this head are stations, warehouses, barges, tugs, trucks, tank-wagons, tank-cars, sidings, storage tanks, and so on.

The total investment given by Ross is 7.4 billion dollars. This estimate may be modified to the extent of discriminating between the present worth of oil-lands and the actual investment made by the

crude petroleum industry in them, and by eliminating from the count the value of inventories which is an asset but not strictly an investment item. The total estimated investment would therefore become: production, 2 billion dollars; transportation, 0.75 billion; refining, 2 billion; and marketing 0.75 billion; making a total of 5.5 billion dollars. Adding the additional investment represented by foreign holdings, the total investment in the American petroleum industry runs somewhere in the neighborhood of 6 billion dollars.

The assets of the petroleum industry, in 1921, as compiled by the National Petroleum News,[1] from annual reports of the companies, was 6 million dollars, exclusive of companies having assets under one million dollars. A classification of assets by sizes of companies is given in Table 3.

TABLE 3.—ASSETS OF THE AMERICAN PETROLEUM INDUSTRY IN 1921, COMPILED FROM ANNUAL REPORTS

Rank	Number of Companies	Assets
Above $100,000,000	12	$3,772,873,637
$50,000,000–$100,000,000	16	1,147,417,412
10,000,000– 50,000,000	36	944,689,248
1,000,000– 10,000,000	28	164,717,016
Total	92	$6,029,497,313

Capitalization of the Industry.—The capitalized value of the petroleum industry is impossible to appraise closely because of the large number of unsubstantial concerns that appear on the record. An attempt has been made to segregate capitalization into the portion pertaining to 250 representative companies, for which the statistical record is practically complete, and the part relating to a much larger number of companies organized during the past few years whose ratio of cash investment to capitalization is not known.[2] The first group of companies represents the conservative and substantial element of the industry, while the second group embraces the newcomers, some legitimate, others merely stock-promoting schemes.

A comparative view of the annual increments to the capitalization of the two groups of companies is shown in Table 4.

[1] May 18, 1921, p. 41.

[2] The analysis in this section makes use of the figures presented by H. L. Doherty in an address, "The Future of the Oil Business," published by the American Petroleum Institute, Dec. 10, 1920.

TABLE 4.—COMPARISON OF THE ANNUAL INCREASE IN STOCK OF 250 ESTABLISHED OIL COMPANIES AND REPORTED ANNUAL CAPITALIZATION OF NEW OIL COMPANIES, 1913–1920 *

(In millions of dollars)

YEAR	250 Established Oil Companies	New Oil Companies
1913	121	No data
1914	115	No data
1915	67	81
1916	272	419
1917	333	840
1918	132	439
1919	707	3786
1920	672†	2787

* Data largely from H. L. Doherty.
† New listings on the New York Stock Exchange in 1920.

The same range of data, but on a cumulative basis, that is, showing the capitalization outstanding at the end of each year from 1913–1920, is presented in Table 5. The capitalization given under the heading of "new oil companies" is, of course, far greater than the paid-in capital.

TABLE 5.—THE GROWTH IN CAPITAL STOCK OF 250 REPRESENTATIVE OIL COMPANIES COMPARED WITH NEW OIL COMPANIES, 1913–1920 *

YEAR	CAPITAL STOCK 250 ESTABLISHED COMPANIES		CAPITAL STOCK NEW OIL COMPANIES
	Millions of Dollars	Per Cent of 1913 Capitalization	Millions of Dollars
1913	885	100	No data
1914	1000	113	No data
1915	1057	119	81
1916	1330	150	500
1917	1662	188	1340
1918	1794	203	1779
1919	2502	283	5565
1920	3174†	358	8352

* Data in part from H. L. Doherty.
† Estimated, see Table 4.

It is apparent from Tables 4 and 5 that there has been a large flow of capital into the petroleum industry during the eight-year period under review. The quantity of capital thus engaged is greater than that listed under the 250 representative companies, but less than the sum of the "250 established companies" and the "new oil companies," since the latter is in part real capital and in part mere paper. If 885 million dollars is accepted as a fair measure of the actual investment in the oil industry in 1913, and the growth in the value of the crude petroleum produced each subsequent year to 1920 is a reasonable indication of the increasing capital requirements of the industry, the actual paid-in capital engaged at the end of 1920 may be calculated to be approximately 5 billion, or 2 billion dollars more than the combined capitalization of the "250 established companies." On the basis of the tangible investment as estimated in the preceding section the actual capital engaged in the petroleum industry is around 6 billion dollars. Thus it would appear that of the 11 billions of capital (actual and paper) that have been involved in oil, 5 to 6 billion represents a tangible quantity, while 5 to 6 billion indicates the magnitude of the oil boom.

In other words, during the period 1913–1920, the actual capital absorbed into the oil industry to support its expansion was something like 4 to 5 billion dollars. During the same period, the money flowing out of the oil industry in the form of dividends was around 1 billion dollars, leaving a difference of 3 to 4 billion dollars as a rough approximation of the net amount absorbed.

Until a few years ago, the oil industry to a large degree financed its expansion out of earnings. Of late, as indicated by the calculations given above, the industry has sought outside capital to help sustain its growth. The ability to finance out of earnings was, of course, curtailed by the heavy taxation and inflated money values growing out of the war period, but with due qualifications for these factors, the recent expansion of the industry is to be credited in substantial degree to the inflow of outside capital. This matter is well known in oil circles: "Up to date each inch of profit has called for a mile of investment to insure there being an inch of profit next year."

Unique Character of Oil.—The estimates given above, as imperfect as they admittedly are, indicate some interesting economic tendencies, which should be studied in relation to certain characteristics peculiar to the development of petroleum. The oil industry has to deal with three characteristics lacking or at least not so highly developed in other industrial enterprises. These are: A rapid depletion of a given source of crude-oil supply, calling for careful accounting if a net profit is to be shown after final liquidation of the

investment; a shifting base of supply, leading to a rapid obsolescence of transportation and refinery installations; and a rapidly changing demand, likewise contributing to a speedy obsolescence of material developments. It is questionable whether these factors have been given due allowance in oil accounting.

Profits of the Petroleum Industry.—The substantial portion of the petroleum industry has proved to be a very profitable activity. The dividends paid annually by 250 representative companies from 1912 to 1919 are given in Table 6.

TABLE 6.—DIVIDENDS PAID BY 250 REPRESENTATIVE OIL COMPANIES BY YEARS, 1912–1919 *

	Dividends, Millions of Dollars	Rate on Capital Stock, Per Cent
1912	64	8.43
1913	93	10.52
1914	75	7.49
1915	78	7.41
1916	121	9.06
1917	150	9.01
1918	159	8.88
1919	166	6.62

* Data from H. L. Doherty, The Future of the Oil Business, Amer. Petr. Inst., Bull. 132, Dec., 1920.

Figures compiled by the Federal Trade Commission [1] for 1919 show higher earnings than those given in Table 6. For example, 82 producing companies, turning out about 16 per cent of the country's total output of crude petroleum and representing an investment of 366 million dollars, showed earnings at the rate of 17.7 per cent upon this investment. Fourteen of these companies, comprising 2.6 per cent of the total production of the group, showed a loss of 2.8 per cent upon their invested capital; while 14 other companies, representing an output of 37.3 per cent of the total for the group, enjoyed profits of over 30 per cent. Thus the tendency for earnings to run higher in the case of larger companies is displayed.

Figures published by the Federal Trade Commission in 1919 covering 138 petroleum refining companies, representing an investment of 2088 million dollars and a refinery consumption of 84 per cent of the country's total, show an average profit of 16.8 per cent. Of this group 28 small companies representing 1.9 per cent of the

[1] Summary of report on the Pacific Coast Petroleum Industry, April 7, 1921.

total investment of the group and 3 per cent of the total refinery consumption of the group, showed a loss of 8.5 per cent; while 28 large companies representing 22.2 per cent of the total investment and 22.5 per cent of the total refinery consumption, enjoyed earnings of 34 per cent. Five companies of the group with an investment of over 100 million dollars each showed an average rate of earning of 24.6 per cent.

Conclusion.—Under the impetus of the profitable nature of the oil business, the industry has expanded with notable rapidity, at first supporting its growth from the wealth created by its own efforts, later calling upon outside capital to lend assistance. Such a course is economically sound during a period of youthful development, if ultimately terminated by a period of productivity in which the flow of capital is reversed. Otherwise the activity will become permanently dependent upon outside agencies of production, an economic anomaly impossible of attainment.

In absorbing of recent years more capital than it has concurrently produced, the oil industry as a whole has considerably over-expanded in respect to the quantity of raw material apparently available for maintaining future operations. If this interpretation is correct, it means either an ultimate financial loss on the part of all activities not soundly developed in respect to raw material, or else such an elevation in price level as will carry for a time much of the unsound development at a reduced capacity. The outcome will probably represent a compromise between the two, with a period of price inflation preceding an era of liquidation, with the possibility of complications resulting in a revision in the economic structure of the entire industry.

CHAPTER II

THE RESOURCE SITUATION[1]

Character of Petroleum.—Crude petroleum is a mineral readily separable into liquid fuels, viscous compounds useful for lubrication, and other products entering into the arts in a number of forms. Chemically, it is dominantly composed of carbon and hydrogen, with a small percentage of nitrogen, sulphur, and oxygen which rank as impurities. The carbon and hydrogen are combined in an almost infinite variety of ways, forming endless numbers of hydrocarbon compounds that challenge the analytical skill of the chemist.

According to Mabery,[2] petroleum is composed of varying mixtures of five major series of hydrocarbons, each with a distinctive relationship between the number of carbon and hydrogen atoms present. These are (1) the paraffin series, C_nH_{2n+2}, comprising the main portions of the gasoline, kerosene, and wax of commerce; (2) the naphthene series, C_nH_{2n}, a closed-chain, or cyclic, type of hydrocarbon, especially characteristic of petroleums yielding asphaltic residues upon distillation; (3) a series of the formula C_nH_{2n-2}, represented particularly in the lighter petroleums, having some viscosity and forming lubricating distillates of light to medium body; (4) a series of the formula C_nH_{2n-4}, typical of the asphaltic petroleums and forming the "constituents of the best lubricants it is possible to prepare from petroleum"; and (5) the aromatic series, C_nH_{2n-6}, cyclic in character like the naphthenes and regarded as a detriment to be removed in refining.

In practice, the various types of petroleum are regarded as falling into three classes: the paraffin-base petroleums, especially rich in the hydrocarbons of the C_nH_{2n+2} and C_nH_{2n-2} series; the asphalt-base, or more properly the naphthene-base, petroleums, consisting mainly of the hydrocarbons of the C_nH_{2n}, C_nH_{2n-4}, and to some degree of the C_nH_{2n-6} series; and intermediate types. The paraffin-base

[1] For a general analysis of the petroleum resource, see Gilbert and Pogue, Petroleum: A Resource Interpretation, Bull. 102, Pt. 6, U. S. National Museum, 1918.

[2] Composition of Petroleum and its Relation to Industrial Use, American Institute of Mining and Metallurgical Engineers, Publ. No. 158, February, 1920.

crudes are rich in gasoline and wax, and yield the bulk of the lubricants produced; the asphalt-base crudes are low in gasoline, yield for the most part notable percentages of asphalt, and although rich in viscous hydrocarbons are not so extensively employed in the manufacture of lubricants; the intermediate, or mixed-base, petroleums share the characteristics of the other two. As may be readily inferred from the carbon-hydrogen ratio, the paraffin petroleums are lighter in weight and more fluid than the asphaltic petroleums.

Occurrence of Petroleum.—Petroleum occurs in the crust of the earth, filling the interstices and crevices in certain types of stratified rocks, particularly sandstones and limestones. It usually holds in solution notable quantities of natural gas under pressure, which adds to the mobility of the oil. Salt water is customarily in close association with the oil, contributing materially to the difficulties of exploitation.

Petroleum is in all probability the natural product of animal and vegetable matter buried in sedimentary formations of the geologic past. The various theories accounting for its origin are notable for agreeing that the oil has migrated from its parent abode to its present points of occurrence. Lighter than water with which the rock formations are usually saturated, the oil and gas tend to migrate upward, working their way to porous beds and following freely their course until arrested by a downward curvature or impervious capping. Thus an oil pool is usually a body of convex shape like an inverted basin, lying under the crest or dome of an impervious layer of rock. Normally the order of occurrence is gas just below the crest, then oil, and finally water buoying up the oil with its support from below. Where water is lacking, as in portions of the Appalachians, the oil tends to accumulate in the structural synclines rather than under the domes or anticlines.

The conditions under which petroleum occurs in the United States have been so extensively studied by methods of geological engineering that the areas of the producing and prospective fields, the number, depth, and thickness of the oil-bearing formations, and the physical characteristics of the productive territory are already known in considerable detail.

Distribution of Petroleum.[1]—The extent of the known oil-producing territory of the United States is given in Fig. 2, while in Fig. 3 are shown the principal pools and producing centers. There are seen

[1] The description of American oil-fields presented in this section is taken with slight modification from a pamphlet entitled "The Outlook for Petroleum," published by Arthur D. Little, Inc., in 1920.

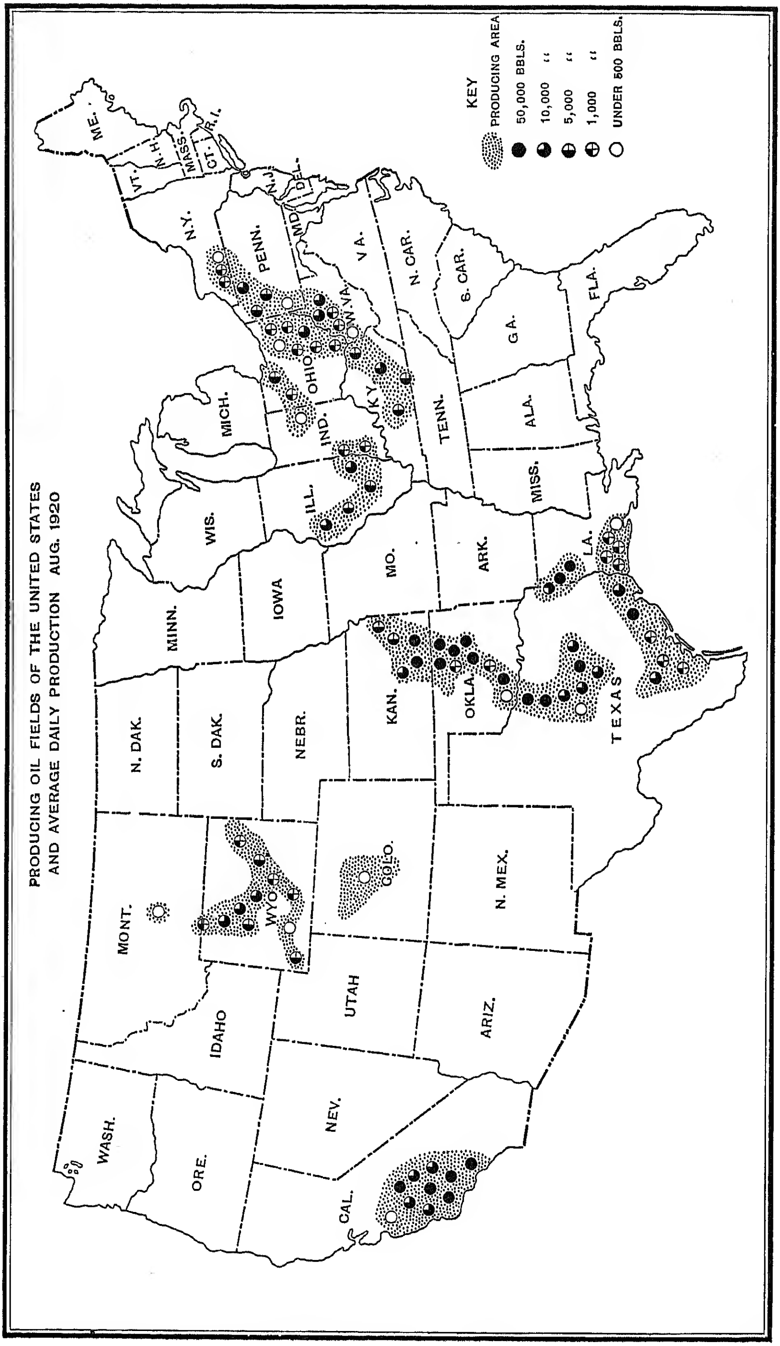


FIG. 2.—Producing oil-fields of the United States and the average daily production in Aug., 1920.

to be seven major fields: The Appalachian, Lima-Indiana, Illinois, Mid-Continent, Gulf, Rocky Mountain, and California. The Texas and Louisiana districts, other than those occurring along the coast which constitute a type to themselves, belong with the Kansas-Oklahoma area as extensions of the great Mid-Continent field. The recent prominence of the Texas-Louisiana group, however, suggests separate consideration.

The Appalachian field is the country's oldest and most consistent producing source. Its history dates back to the discovery well in 1859 on the Drake farm at Titusville, Pennsylvania, which marked the beginning of the American petroleum industry. Little or nothing was known of oil geology at the time and the complexities of the Appalachian structure were slow in being worked out. In consequence its numerous pools were located at scattered intervals of time and for forty years new production continued to more than offset the waning output of the older districts. Since 1900, however, the net tendency has been reversed. Production in this field has been on the down grade and its output to-day is little more than half the figure that characterized the field at its prime.

The Appalachian field comprises a great spoon-shaped structural basin with limits established without possibility of important extensions. Within this basin the oil and gas, where accompanied by water, accumulated beneath the crests of secondary folds; but where water was absent the two parted company, the gas rising to the crests and the oil sinking to the depressions. The bottom of the basin represents the most productive area and underlies the West Virginia Panhandle, where the basin has a width of about 150 miles. To the northeast and the southwest it not only narrows but becomes less productive until it terminates in southwestern New York and in a scattering of outliers in Kentucky and northern Tennessee.

New pools in the Appalachian basin continue to be located from time to time, particularly in Kentucky, but the structure has been determined and tested to such a degree that considerable extensions are extremely improbable. The chief factor responsible for the sustained output is that pumping may be profitably conducted to the very last of the oil underground. Thus the larger share of the field's output is drawn from a multitude of small wells intermittently pumped from sump accumulations.

The Lima-Indiana field, the second oldest source of American petroleum, affords an interesting variant from the usual occurrence in which the oil is found in porous sandstones or "sands." There the oil occurs in limestone. In a regional sense, this field holds a structural relationship to its neighbor to the east. The Appalachian

field occupies a geosyncline, or great structural basin, between the mountainous Appalachian uplift on the east and the gentle Cincinnati uplift on the west. The Lima-Indiana accumulation of oil was found toward the crest of the Cincinnati uplift underlying subordinate domes where the limestone had suffered alteration to a porous magnesian variety. The field was discovered in 1886, reached its crest of production two decades later, and has been on the decline ever since. The structure has been worked out and the possibilities explored to such a degree that nothing other than a continued decline to extinction may be expected.

The Illinois field includes the great structural arches next to the west and the pools underlie the secondary convexities in the major system. Drilling quickly took the measure of the field, once it was discovered in 1905, and brought it to its prime in five years. Since 1910 it has been steadily declining and no revival is in prospect.

The Gulf Coast field, discovered in 1900, reached its apparent prime only five years later and thereafter declined with minor fluctuations until the bringing in of new pools in 1913 renewed its vigor. In consequence its current rate of output is nearly three times that of its apparent declining years and nearly equal the peak of fifteen years ago. The pools are found beneath a peculiar type of local uplift, called domes, similar to those in which salt and sulphur occur in commercial quantities. These domes are not a definite part of any great structural system, but are of local development and usually give no surface indications of their presence. The discovery of new pools, accordingly, is largely contingent upon fortunate drilling. This is what brought about the rejuvenation of the field, and the history of the past few years may repeat itself. But the area on the whole is not extensive and, excepting the famous Spindle Top pool, the individual occurrences are not sensationally large; so it is quite improbable that the field will ever substantially enlarge upon its present output.

Two small pools in Colorado discovered in 1876 first called attention to the existence of a Rocky Mountain field. Their combined output, however, was insignificant until the discovery of the Salt Creek pool in Wyoming renewed interest in the field and led to a steadily increasing production which in 1920 approached the 20 million barrel mark. The Rocky Mountain field is still undoubtedly in its youth and susceptible of extension. Considerable effort has been expended in determining possible oil structures not only in Wyoming, but in Montana, Utah, and New Mexico as well, where general geological conditions are favorable to the presence of oil. The mode of occurrence conforms to the structural anticlines that

wall off the great structural basins, and the boldness of the exposures simplifies the work of interpreting the latent possibilities of the field. Without specifying the results in detail, they may be said to hold out hope of finding additional sources, but structures on the Appalachian and Mid-Continent scale of magnitude are lacking. From the surveys made it is possible to appraise the future of the field in a general way and to venture the prediction that the output can scarcely be expected to exceed 40 million barrels as an annual maximum.

The California field was brought into action in 1898 and has been steadily increasing in importance ever since, with a temporary slump in 1915. The present annual production rate of approximately 100 million barrels exceeds the combined output of the five fields thus far discussed, and represents nearly a quarter of the country's total. The areal extent of the fields is not in keeping with its producing importance, but the pools are characterized by a tremendous and sustained capacity. The limits of the field can scarcely be said to have been entirely determined, but the possibility of finding a successor to the Midway Sunset district is distinctly remote and more than passing significance is to be attached to the general flattening of the production curve since 1913. (See Fig. 21, p. 55.) On a larger scale, the field promises to reproduce the past history of the Lima-Indiana and Illinois fields from around 1902 and 1908 respectively, which is to say that the next three years will see the field set for a slow but sure decline.

The Mid-Continent field is the latest and greatest of the country's producing sources to come into prominence. The principal productive area extends from Kansas City south across eastern Kansas and Oklahoma with extensions into northern and central Texas and northwestern Louisiana, which are commonly treated separately in view of their recent prominence. After a sensational early development between 1903 and 1907, the field steadied down to a substantial growth during the next few years only to have a second sensational boom ushered in by the phenomenal Cushing district in 1914. Recently the center of attraction has shifted to the pools in Texas and Louisiana.

The mode of occurrence is definitely related to the structure which, unlike that of the Gulf Coast area, is for the most part discernible at the surface. It is generally conceded that such new pools as await discovery in Kansas and Oklahoma are in the nature of outliers. The Texas and Louisiana extensions unfortunately have shown themselves to be disappointingly short-lived with a disposition to go to water quickly. Unless there are unknown reserves of a different order, a prospect out of keeping with what is already known of

the geologic structure, or unless important extensions can be quickly found to the northwest or the southwest, which seems unlikely on a large scale, the increment added from year to year by outliers cannot long continue to offset the waning output of the great pools toward the center of the field. What has been said of the great California field bids fair to hold even more assuredly of the still greater Mid-Continent source. Production here has been unduly forced by the oil-boom of 1919–20 and is misleading; but this cannot continue, and the production curve is due shortly to round off and begin a long course downward like that of the fields to the east.

From this brief review of the producing fields, it is seen that of the seven domestic sources three are in a state of hopeless decline; one is largely an unknown quantity; the two greatest are at their best; and just one, the Rocky Mountain field, is assuredly still in its youth.

The Unmined Supply of Petroleum in the United States.[1]— The portion of the petroleum resource of greatest interest is that not yet used, for the unmined supply must support the future. With the growth of geological knowledge regarding the character and location of oil-bearing formations, attention was naturally attracted to estimates of the oil underground; and as early as 1908 Day, then in charge of the petroleum statistics in the U. S. Geological Survey, calculated the total quantity of oil originally available in the ground in the United States as ranging between a minimum of 10 billion barrels and a maximum of 24.5 billion barrels. (For purposes of comparison it should be recalled that our present annual requirements are slightly above one-half billion barrels.) Day's estimate was based upon data accumulated by the Survey in the course of extensive field investigations, but at the time the drill had not penetrated some of the richest oil-pools in the country.

Again, in 1915, Arnold revised the inventory made by Day, in the light of the additional engineering data and the advance in geological science that had developed in the meantime. And the period between 1908 and 1915, it should be noted, was marked by an intensive development in which new oil-producing territory was opened up and the older areas were more closely studied. Arnold placed the original supply at approximately 9.1 billion barrels, thus somewhat reducing Day's minimum.

A third estimate was made by the geologists of the oil and gas section of the U. S. Geological Survey in 1916 in response to a Senate resolution, and this estimate placed the original supply at 11.2 billion

[1] A further discussion of this topic will be found in Gilbert and Pogue, America's Power Resources, New York, 1921, pp. 249–258.

barrels. In the spring of 1917 the matter was carefully reconsidered "with marked conservatism" by the same geologists, each studying the regions with which he had field acquaintance, with the result that the original supply was reduced to 10.1 billion barrels.

Finally, in late 1918, the whole appraisal was recalculated by David White and his associates on the Geological Survey, in the light of still further information, and the conclusion was reached that the original supply of available oil in the ground was approximately 11.3 billion barrels.[1]

These five estimates may be tabulated for comparison:

TABLE 7.—ESTIMATE OF THE ORIGINAL SUPPLY OF CRUDE PETROLEUM IN THE UNITED STATES

Year	Unmined Supply (*In billions of barrels*)
1908	10–20.4
1915	9.1
1916	11.2
1917	10.1
1918	11.3

The striking feature of the comparison is that the development work of the ten-year period, which so markedly increased the *production* of crude petroleum, did not materially enlarge the apparent size of the resource.

The dependability of such estimates has been widely questioned, and none would be readier than the sponsor geologists themselves to disclaim exactitude or finality for the figures. But the fact remains that successive estimates of the unmined supply, in spite of the enlarging acreage sounded by the drill, do not materially increase the total. And while the margin of error may be conceded to be as much as 50 per cent, or even 100 per cent to allow for contingencies, the important point is the smallness of the domestic resource upon which our petroleum requirements are dependent.

Up to January 1, 1921, the United States has produced 5.4 billion barrels of petroleum. Subtracting this quantity from the original supply of 11.3 billions, we have left as a working reserve 5.9 billion barrels, with an annual consumption requirement running well above the half billion mark. The Chief Geologist of the U. S. Geological Survey in 1920 was quoted as believing it fair to consider 6.5 billion

[1] David White, The Unmined Supply of Petroleum in the United States, Society of Automotive Engineers, February, 1919.

barrels as conservative and 8 billion as an improbable maximum.[1] But double or even treble the size of the reserve, and the resource situation still remains serious, if not critical. Even repudiate entirely the geologist and all his works, and there still remain the production facts to reckon with, which tell us that the rate of extraction must soon slow down, irrespective of the unmined supply.

A decline curve for the country as a whole, picturing the resource depletion, is presented in Fig. 4.

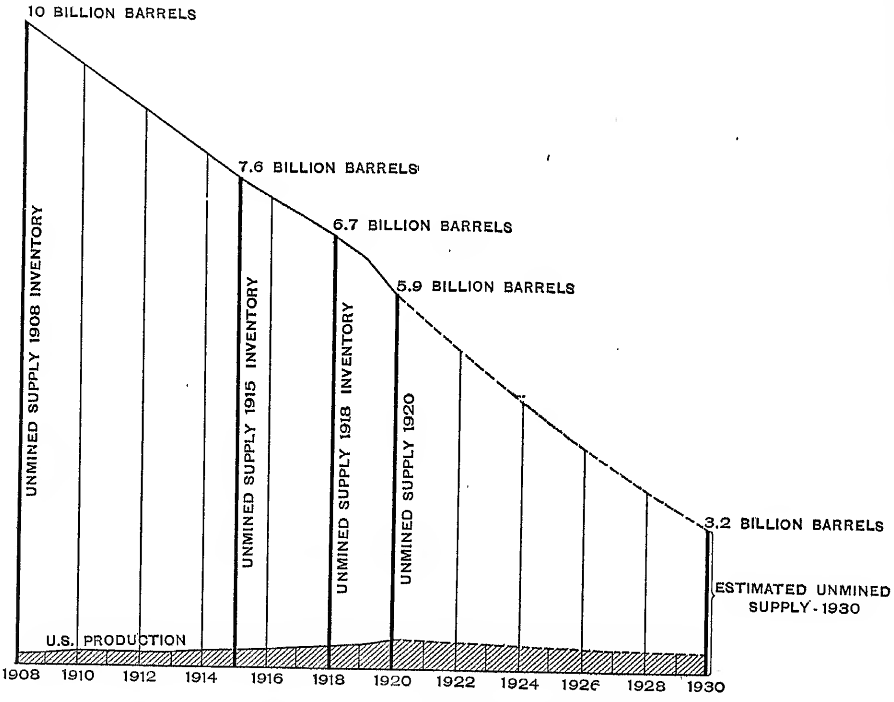


FIG. 4.—Estimated unmined supply of crude petroleum in the United States. After Pogue and Lubin, U. S. Fuel Administration; data for 1908–1920 from U. S. Geological Survey; projection 1920–1930 from Bates and Lasky, Amer. Inst. Min. and Met. Eng.

Distribution of Unmined Supply.—The original quantities of oil underground in the various producing fields, as well as the extent to which the different areas have been exploited, are dissimilar, and it is therefore of interest to review the distribution of the remaining supply. The resource situation by fields, on the basis of the esti-

[1] George Otis Smith, A Foreign Oil Supply for the United States, Publ. No. 157, American Institute of Mining and Metallurgical Engineers, January, 1920.

mates of the U. S. Geological Survey, is accordingly presented in Table 8 and interpreted graphically in Fig. 5.

TABLE 8.—THE QUANTITY OF PETROLEUM EXTRACTED AND STILL AVAILABLE IN THE OIL-FIELDS OF THE UNITED STATES
(Data from the U. S. Geological Survey)

Fields	Original Supply (Millions of Barrels)	Extracted to Jan. 1, 1921 (Millions of Barrels)	Per Cent Exhausted	Available Jan. 1, 1921 (Millions of Barrels)	1920 Production (Millions of Barrels)
Appalachian	1,772	1281	72	491	30.5
Lima-Indiana	488	455	93	33	3.1
Illinois	473	321	68	152	10.8
Kans.-Okla	2,716	1251	46	1465	144.2
N. Texas	479	217	45	262	71.0
N. Louisiana	191	138	72	53	33.9
Gulf	1,054	351	33	703	26.8
Wyoming	440	70	16	370	17.2
California	3,364	1321	39	2043	105.7
Others	361	11	3	350	0.2
Total	11,338	5416	48	5922	443.4

Interpretation of Supply.—It must not be supposed that the unmined supply can be divided by the current production and a figure obtained that will even approximate the life of the resource. The estimates were originally drawn on the basis of the present factor of recovery, which, as will appear in Chapter 28, is unduly low, and upon the present price level, which has not stimulated the utmost extraction of the oil. With increasing dearth and rising prices, oil not now economically recoverable will be brought to the surface, the supply of oil will be enlarged by more efficient methods of mining, and a relatively smaller volume of oil will be made to perform a given service through more effective refining and application. The supply, therefore, may be expected to spread over a greater period of time and a wider range of essential service than would appear from an unqualified consideration of the figures alone.

What the estimates of the unmined supply do show, therefore, is not impending exhaustion, but the imminence of a period of economic and technical proficiency in bringing the remaining supply of our crude petroleum into effective service. The arrival of this period may be expected to usher in changes of far-reaching significance in the structure and functioning of the petroleum industry.

Oil in Foreign Countries.—The limited size of the oil reserve of the United States, and the degree to which it is already depleted, naturally direct attention to foreign oil-fields. The petroleum resources of most of the rest of the world are far less thoroughly measured than those of this country; although sufficient is known perhaps, to lead to an approximation of the world's reserve, if leeway be allowed as a margin of error.

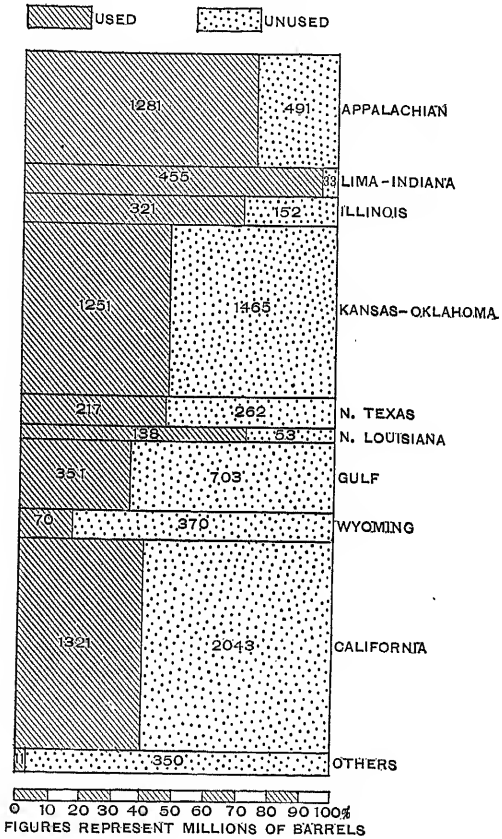


FIG. 5.—The petroleum reserve of the United States by fields, showing the portion used to Jan. 1, 1921; data from U. S. Geological Survey.

There is little, if any, doubt but that the dominant portion of the oil in the crust of the earth underlies three broad areas: the United States; the Caribbean basin, including Mexico, Central America, Colombia, and Venezuela; and the Caspian-Black - Sea - Eastern Mediterranean region, including southern Russia, south-western Siberia, Mesopotamia, Persia, and Palestine. These three major oil areas have an original oil content that for purposes of comparison may be regarded as of the same order of magnitude, or roughly 10 billion barrels each. While such figures are doubtless highly speculative, they are better than purely qualitative terms and are reasonably satisfactory as a basis of discussion. Elsewhere in the world there may be an additional 10 billion barrels, thus raising the world resource to the neighborhood of 40 billion barrels or so, of which the United States has used up approximately half of the 10 billion barrels falling immediately to her share.

The general distribution and magnitude of the principal petroleum reserves of the world have been estimated by Eugene Stebinger, of the Foreign Mineral Section of the U. S. Geological Survey, and the results of these estimates have been published and discussed by David White.[1] A map compiled by the Survey showing these estimates in diagrammatic form is presented in Fig. 6, on which the estimated reserves are shown by circles proportional to the quantitative importance of the various regions. The data upon which this map is based are shown in Table 9.

Table 9.—Preliminary Estimate of the Petroleum Resources of the World, after Stebinger of the U. S. Geological Survey

Regions	Relative Magnitude	Approximate Quantity in Millions of Barrels
United States and Alaska	100	7,000*
Canada	14	995
Mexico	65	4,525
Northern South America including Peru	82	5,730
Southern South America including Bolivia	51	3,550
Algeria and Egypt	13	925
Persia and Mesopotamia	83	5,820
S. E. Russia, S. W. Siberia and the region of the Caucasus	83	5,830
Rumania, Galicia and Western Europe	16	1,135
Northern Russia and Saghalien	13	925
Japan and Formosa	18	1,235
China	20	1,375
India	14	995
East Indies	43	3,015
Total	615	43,055
Total eastern hemisphere	303	21,255
Total western hemisphere	312	21,800
Total north of the equator	520	36,400
Total south of the equator	95	6,655

* Since this table was completed the reserve in the United States has been drawn upon to the extent of over 800 million barrels, thus being reduced to about 6000 million barrels as of Jan. 1, 1921.

It should be noted that the totals given in the table "suggest a surprisingly even balanced distribution of oil between the eastern

[1] The Petroleum Resources of the World, Annals of the American Academy, May, 1920.

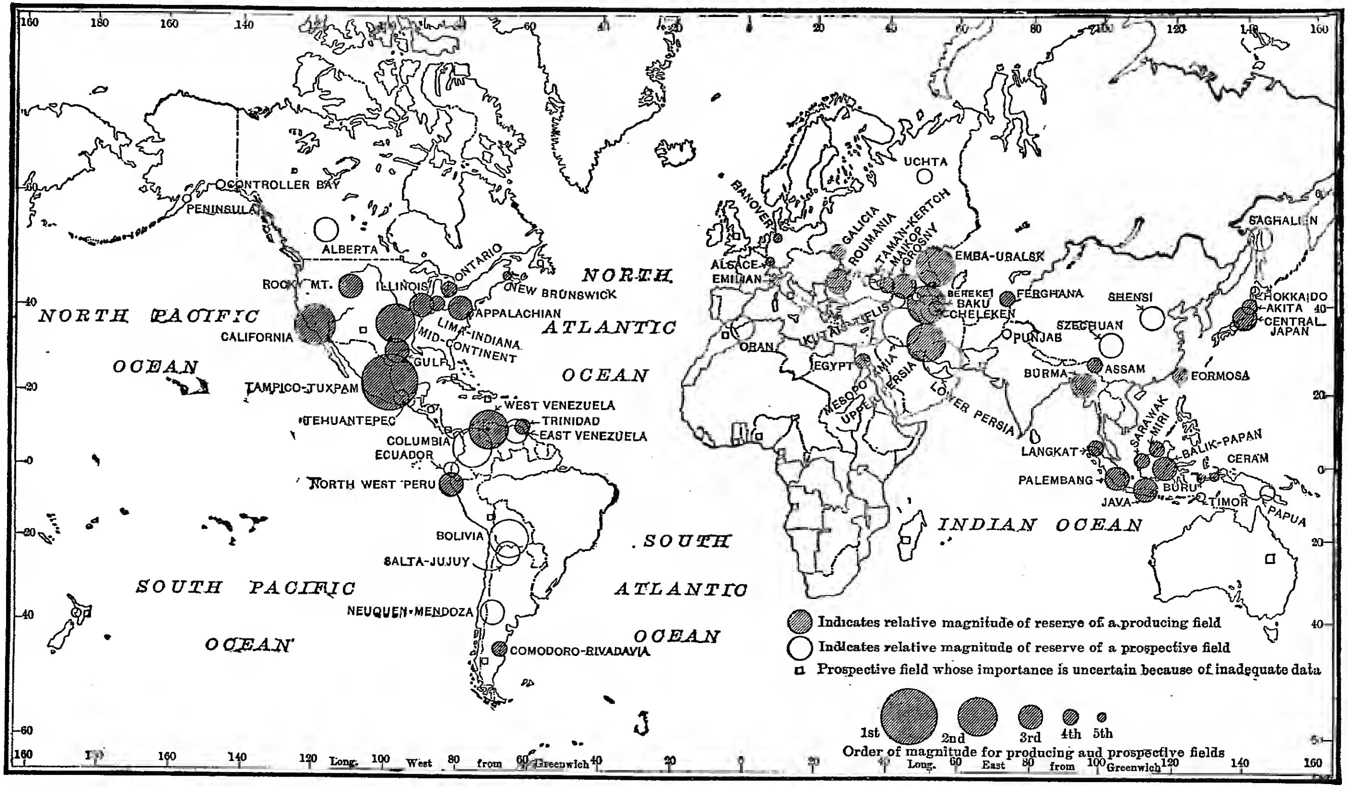


FIG. 6.—World map of developed and potential petroleum reserves. Prepared by the U. S. Geological Survey, 1919; compiled by Eugene Stebinger.

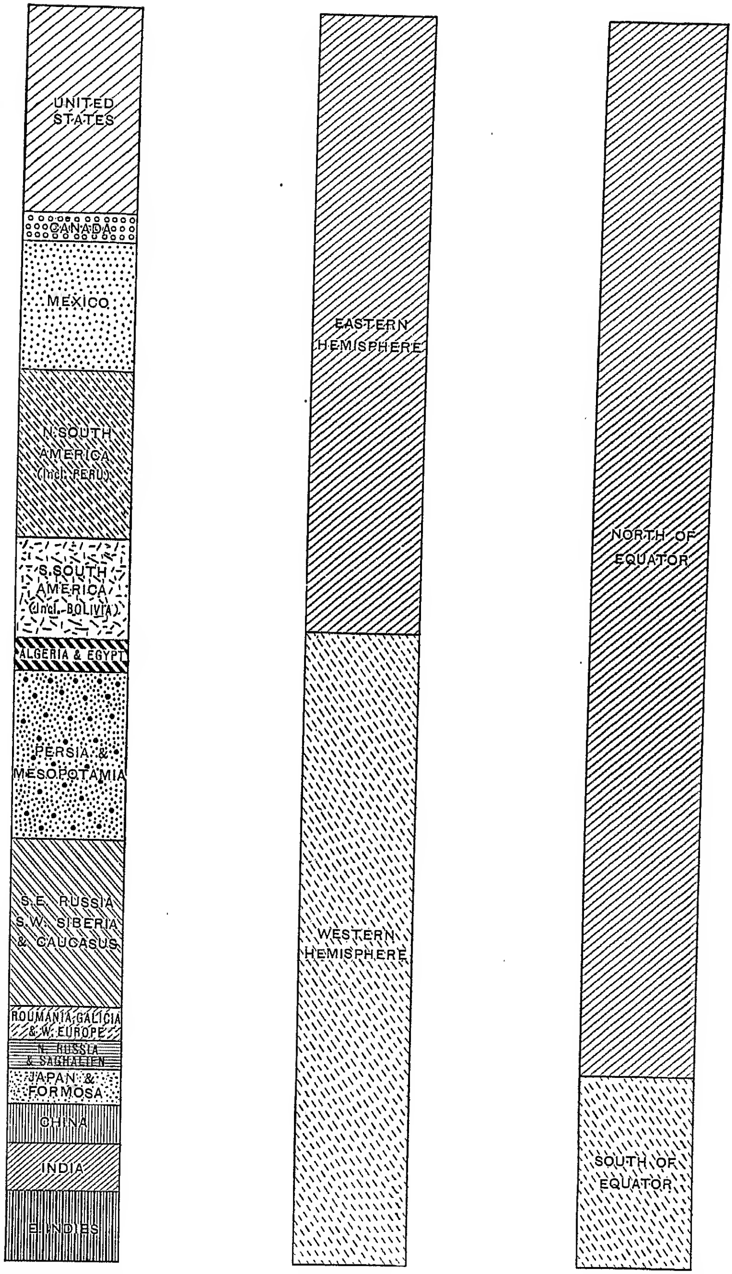


Fig. 7.—Relative petroleum resources of the world, after data compiled by Stebinger, U. S. Geological Survey.

and western hemispheres, and, as with the distribution of the world's coal reserve, a great preponderance of tonnage north of the equator." In discussing these estimates, White calls them conservative not only because they represent "the cautious judgment of a well-trained and experienced oil and gas geologist based on the best information available at the present time, but also for the reason that the value assigned to the oil-fields of the United States is conservative." White goes on to say that "these forecasts, or geological guesses, formulated conservatively with the probability that deficiencies will be very much more than compensated by excesses, lead one to conclude that there are probably 20 billion barrels of oil available in the world in addition to the 43 billion barrels contained in the regions covered by Mr. Stebinger's estimates quoted above, or as much in round numbers, as 60 billions of barrels in all."

The figures shown in Table 9 are graphically expressed in Fig. 7, which throws the estimates into perspective.

Undoubtedly the estimates of the world's reserve as here given are the most general approximations merely, but at the least they have sufficient substance to show where the leading centers of oil production are likely to be in the future; and they serve to emphasize the important draft already made upon the portion underlying the United States. With due qualification they must be given consideration in matters involving the industrial and international policy of this country.

CHAPTER III

THE TREND OF OIL-FIELD DEVELOPMENT

THE exploitation of petroleum involves three successive stages: exploration, to locate oil-bearing territory; development, to bring the oil into production; and production, to reduce the oil to possession. A sustained output of petroleum necessitates vigorous extension of productive territory, consistent drilling of the area so proven, and steady withdrawal of the oil brought into production. The first two factors are progressive, while the third is cumulative. At any given moment, the country's output of crude petroleum is a function of the number of producing wells and their average flow; but the course of production is dependent in addition upon the rate of drilling and the extension of territory suitable for drilling, since the average flow of old wells is a decreasing function.

Exploration, or the extension of oil-bearing territory, is highly individualistic and is prosecuted mainly by an activity picturesquely termed "wildcatting," whereby wells are drilled in regions of promise by individuals, corresponding somewhat to the prospectors in metal-mining, who are spurred on by the notable gain attaching to lucky strikes. To a large degree, therefore, the pioneer work of exploration falls to the lot of individual initiative and enterprise, the organized agencies of production tending to center their attention upon the acquisition and drilling of land in proven territory. The cost of exploration, especially that of negative exploration, does not fall heavily upon the books of the industry proper, being carried chiefly at the expense of the speculative fringe of operators playing a hazardous game of chance. There is no basis for estimating the cost of exploration in the aggregate, as it does not enter completely as a tangible factor into the cost sheets of productive wells.

Development, or the drilling of proven territory, is the factor of prime importance in compensating for the normal declining tendency of producing wells. The degree to which the country's production of crude petroleum is dependent upon the new wells drilled is indicated by figures compiled by the American Petroleum Institute which show that the output of twenty large producing companies in 1919 was 172 million barrels, of which 45 million, or 26 per cent, came from

wells completed in that year. It would appear from these figures that roughly three-quarters of our annual production of oil is now coming from old wells, and one-quarter from new wells.

Technology of Oil-field Development.—The technical features of drilling and production are complex and need be touched on here only in so far as they bear upon the economic problems. Oil, of course, is won from wells drilled vertically into the crust of the earth to a depth of usually from one thousand to several thousand feet until the productive stratum is tapped. Two methods of drilling are in vogue: the older, and more widely employed, is the standard method, which utilizes a churn drill that pounds its way downward; the newer and more efficient in formations that are not too resistant is the rotary method, employing a drill that bores its way downward. The drill hole must usually be protected, either in whole or in part, by the insertion of iron piping called casing, which prevents the inflow of water or the improper escape of the oil and associated gas.

The completion of an oil well is a costly process running usually into tens of thousands of dollars, as it involves a large expenditure of labor, power, steel, and time as well as a considerable outlay of capital. In 1913 the average 2500-foot well in Oklahoma or Kansas could be drilled and equipped for $12,000; in 1920 a similar well cost $32,000. In Table 10 is shown an analysis of the items of cost entering into the drilling of a typical oil well 2500 feet in depth under average conditions with cable tools in the Mid-Continent field.

TABLE 10.—COST OF DRILLING AND EQUIPPING A TYPICAL 2500-FOOT WELL IN THE MID-CONTINENT FIELD, 1913–1920

(Data from Bates and Lasky, compiled by F. W. Swift)

(In thousands of dollars)

Items	1913	1914	1915	1916	1917	1918	1919	1920 *
Casing	5.03	4.87	4.82	6.55	9.26	10.3	13.0	13.0
Contract drilling	2.03	3.38	3.65	4.38	5.00	5.63	7.75	7.75
Labor	1.22	1.32	1.35	1.45	1.77	2.10	2.83	3.40
Other	3.52	3.74	3.74	4.27	5.42	6.53	7.92	7.85
Total	11.8 †	13.3	13.6	16.6	21.4	24.6	31.5	32.0

* Estimated. † Corrected total.

The cost of drilling, also, increases rapidly with depth; roughly speaking each thousand feet below a depth of three thousand doubling the cost of the well. This factor of accelerating cost with depth has far-reaching significance in connection with future development

work as shallower deposits become progressively exhausted; it also represents a factor limiting the depths to which deposits may be commercially exploited.

Once the oil is reached, there are many natural and artificial factors entering into the rate of production such as the pressure under which the oil occurs, its viscosity, the thickness and extent of the reservoir rock, the porosity and structure of the reservoir rock, the depth of the well, the distance from other wells, the condition of the equipment, the degree of competition, the price of oil, and many others.[1] In general, wells show an initial production which rapidly declines to a settled production which in turn gradually tapers off to an ultimate output so low that the well is abandoned. New wells are customarily reported in terms of their initial daily production, and this figure must be duly discounted in estimating the future output of the well. For instance, the average well in many parts of Oklahoma will produce daily during the first year of its life about 25 per cent of its initial daily production. Wells in some localities show an initial daily production running up to thousands of barrels, but the average initial daily production in the older fields is much less. Thus in 1918, the average initial production in the Appalachian field was 16.2 barrels; in the Illinois field, 21.1 barrels; in the Mid-Continent field, 100.6 barrels; and in the Gulf field 331.9 barrels. During the same year the average daily production of all wells was 4.7 barrels.

Cost of Production.—The cost of producing a barrel of oil is an important figure which unfortunately is not precisely known in many, if not the majority of, field operations. The price of crude petroleum does not bear the same degree of systematic relationship to the cost of production as is the case with ordinary commodities; the price of crude petroleum fluctuates independently of cost and may fall below the latter in times of overproduction. The unit production cost for a representative company operating in the Mid-Continent field, with a daily production of over 2000 barrels, was 2 dollars per barrel in 1919. This company realized 2 dollars and 40 cents a barrel on its sales, thus making a net profit of 40 cents a barrel. The operating costs of this company are given in Table 11.

The high proportion of the total cost that is credited against indirect and non-tangible elements such as depletion, dry holes, etc., is worthy of special note. In many operations the cost is incorrectly calculated through omission of these items and false book profits are shown.

[1] Ralph Arnold, The Petroleum Resources of the United States, Economic Geology, vol. 10, 1915.

TABLE 11.—ANALYSIS OF OPERATING COSTS IN 1919 OF A REPRESENTATIVE PRODUCING COMPANY IN THE MID-CONTINENT FIELD

(Data from Bates and Lasky)

Direct lifting expense	22.50 per cent
Depletion of property	18.50 " "
Depreciation of physical equipment	15.60 " "
Non-tangible development expense	14.55 " "
Dry holes and abandonments	13.20 " "
General expense	6.40 " "
Year's proportion of bonus	5.13 " "
Rentals of undeveloped acreage	4.12 " "
Total	100.00 per cent

The most important direct cost in producing oil is the lifting expense. The cost of lifting a barrel of oil for a representative company in the Mid-Continent field during an average month of 1920 was 63 cents. This figure is fairly representative of the field as a whole. An analysis of the components of this item of cost is given in Table 12.

TABLE 12.—ANALYSIS OF THE UNIT LIFTING COST OF A REPRESENTATIVE PRODUCING COMPANY IN THE MID-CONTINENT FIELD FOR AN AVERAGE MONTH IN 1920.

(Data from Bates and Lasky)

Items	Cents per Barrel	Per Cent of Total
Labor	17.8	28.25
Overhead	15.6	24.75
Repairs	13.2	20.98
Teaming	8.8	13.96
Supplies	6.5	10.31
Cleaning	1.1	1.75
Total	63.0	100.00

According to figures compiled by the Federal Trade Commission [1] covering the majority of wells in California, the average cost of producing a barrel of oil was 27.4 cents in 1914, and 46.3 cents in 1919, an increase of 69 per cent. The component of the total cost

[1] Summary of report on the Pacific Coast Petroleum Industry, Washington, April 7, 1921.

falling under the head of lifting expense, including all expense incurred in raising the crude petroleum from the well and delivering it into the producer's storage tanks, varies widely. In the case of flowing wells this expense ran as low as 1 cent per barrel with one company in 1914; while for very deep wells requiring pumping this item amounted to as much as 72 cents as shown by the records of another company for 1914. The cost of production in California, as elsewhere, shows a consistent relationship to the size of the operations, as indicated in Table 13.

TABLE 13.—COST OF PRODUCING A BARREL OF OIL IN CALIFORNIA IN 1914 AND 1919, BY SIZES OF COMPANIES

(Data from Federal Trade Commission)

Size of Company in Barrels of Annual Production	Cost of Production in Cents per Barrel	
	1914	1919
1,000,000–250,000	28.6	49.9
250,000– 50,000	49.3	74.9
Under 50,000	72.1	121.2
Average of all	27.4	46.3

The Competitive Factor in Production.—In the drilling and production of oil there is a unique competitive factor at work characteristic of no other substance, which has a far-reaching effect upon the economic behavior of petroleum and serves to explain its economic peculiarities. This factor arises from the competitive extraction of a liquid from a common reservoir, as exemplified in the conditions prevailing in the average oil-pool. Fig. 8, for example, represents 640 acres of oil land, where 16 companies own 40 acres each. This is by no means an exaggerated conception, since properties of 10 acres or even less are not uncommon. When A drills a well in the southeastern corner of his lot, B, E, and F, must drill offset wells or suffer

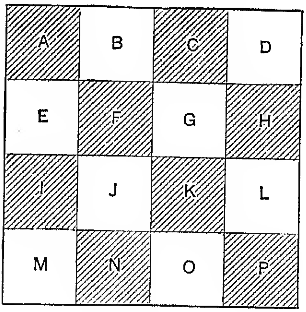


FIG. 8.—Hypothetical square mile of oil-bearing territory, showing checkerboard disposition of small property holdings—the fundamental cause of overproduction and waste. (Adapted from Requa.)

their property to be drained. For every corner well so drilled, three other corner wells must be put down; and for every line well, an offset line well must be drilled as protection. In time of overproduction, operator F cannot afford to shut down, because A, B, C, G, E, I, J, or K, or any combination of them, may refuse to do likewise, and oil in the ground of F will be extracted from his property. Because of this condition, curtailment in output in practice comes only as a result of a natural decline in the flow of producing wells. "The small producer, no matter what happens, is between the upper and nether millstones. He is powerless to control his own or his neighbor's production. . . ."[1]

The small property, overlying the oil-bearing reservoir in numbers and forming a checkerboard pattern; is prevalent in all the producing fields. Fig. 9 represents a typical portion of the Cushing pool in Oklahoma, from a map published by the U. S. Geological Survey; the concentration of wells along the property lines is striking. The conditions outlined in the preceding paragraph as characteristic of a hypothetical square mile of territory pervade the whole production of petroleum. Competition between small holdings is inevitable and leads to the same results in the mass as it does in the simple group of properties. In the words of Max W. Ball,[2] "Ignorance there may be, carelessness there undoubtedly is, but back of ignorance, of carelessness, of reckless, headlong methods, is the real cause—the fact that the average holding is so small that speed is the owner's sole protection. Let him be careful if he can; let him be economical if he can find a way; but careful or careless, reckless or conservative, he must be speedy if he would survive. The small holding is his master."

The development and production of petroleum, therefore, are dominated by a factor which arises from a reaction between human nature and the geological occurrence of petroleum and has a significance and importance difficult to exaggerate. This factor must be held in mind in viewing any phase of the oil industry; the economic aspects of petroleum cannot be appraised without its proper evaluation. Its effect has been to drive the production of petroleum forward insistently and without respite, and to render petroleum peculiarly resistent to retardation in periods of overproduction and times of reduced demand. It has contributed to making the United States the greatest producer of oil in the world, but it has assisted in reducing her reserve of oil by half. It has helped to

[1] M. L. Requa, Petroleum Resources of the United States, Senate Document 363, 64th Congress, 1st session, 1916, p. 16.

[2] Adequate Acreage and Oil Conservation, Proc. Am. Min. Cong., Nov., 1916, pp. 322–333.

sustain the phenomenal growth of automotive transportation by providing the basis of motor-fuel in ever-increasing quantities;

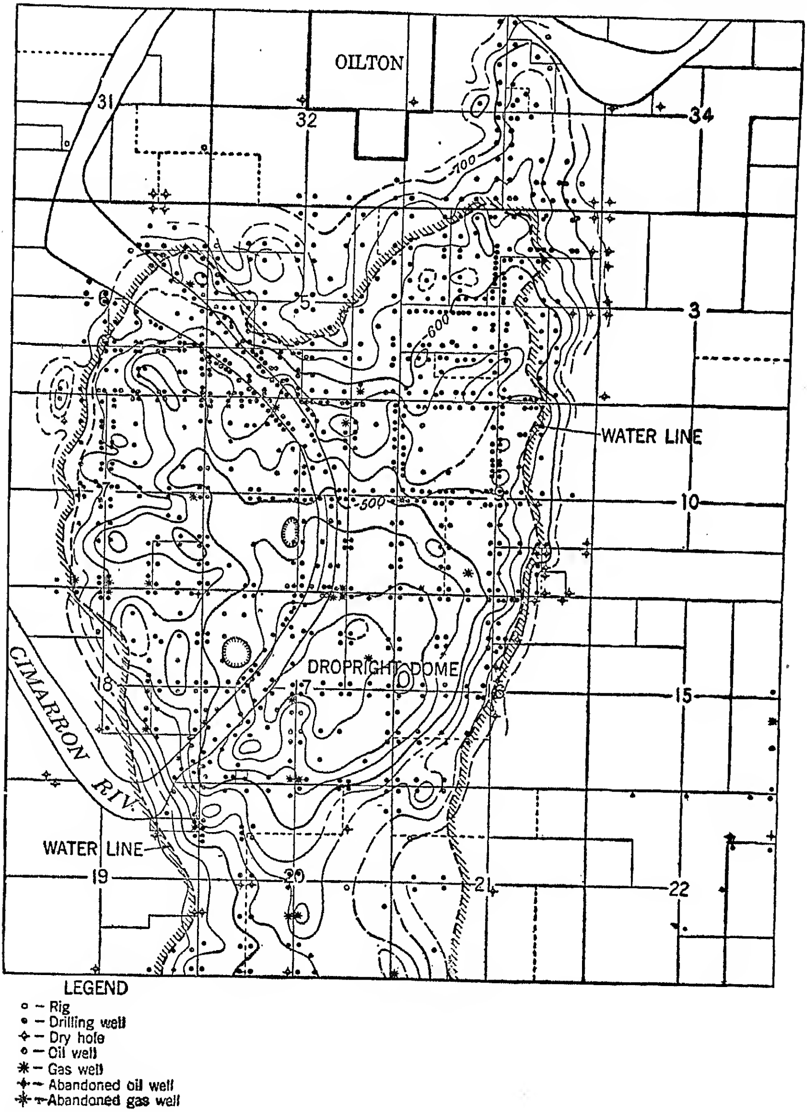


FIG. 9.—Map of a portion of the Cushing oil pool, Oklahoma, showing the subdivision of the area into small properties and the resulting grouping of walls along the property lines. (After Beal, U. S. Geological Survey.)

but it has hidden the necessity for the automotive engine to evolve to higher levels of thermal efficiency and to lessened dependence

upon volatility in fuel. It has stimulated wide fields of application and supported important lines of industrial development; but it has created imminent problems in readjustment and reconstruction. Whether for better or worse, the effect of the competitive small holding in oil-field development has been extensive and profound.

Bearing of Geology upon Oil-field Development.—During the past fifteen years the science of geology has been applied in growing degree to the location of the structures underlain by oil and to the measurement of underground conditions as a guide to exploitation. "One need look back only a few years—a very few years—to a time when oil men would have laughed with scorn at the statement that there was any connection whatever between geology and the oil industry. To-day every important company in the world has its corps of oil geologists, and upon their opinion depends the investment of most of the millions of dollars which annually go into prospecting and development work."[1]

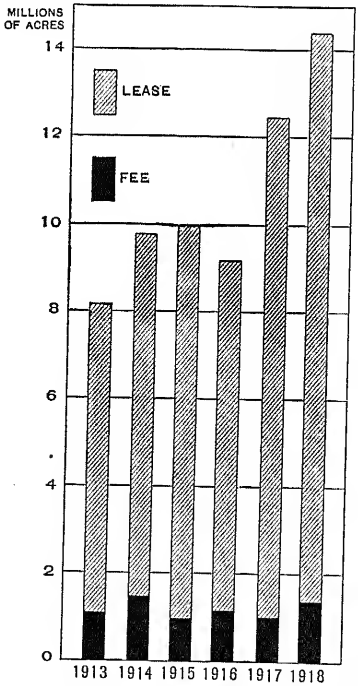


FIG. 10.—Oil acreage in the United States by years, 1913–1918; data from U. S. Geological Survey.

It is difficult to appraise closely the effect of geology upon the development of the petroleum resource. Wherever used, it has greatly increased the productivity of the drill and led to a fuller control of the natural extractive forces as well as alleviated the harmful effects of water, though seriously handicapped in the latter respects by economic forces arising from the small holding which worked at cross purposes with it. The widespread employment of geology has also apparently speeded up the rate of production as well as reduced its unit cost. Another important service rendered by geology in the oil-fields has been in the direction of measuring the unmined supply, with results by which both industrial and national policy will be guided in growing degree in the future.

[1] Ralph Arnold, Oil Geology in Relation to Valuation Work, Bull. Geol. Soc. America, vol. 31, 1920, pp. 433–440.

TABLE 14.—OIL ACREAGE IN THE UNITED STATES

(Data from the U. S. Geological Survey)

(In thousands of acres)

	Fee	Lease	Ratio of Fee to Lease	Total
1913	1051	7,088	14.8	8,139
1914	1445	8,342	17.3	9,787
1915	988	9,014	11.0	10,002
1916	1169	8,025	14.6	9,195
1917	1019	11,436	8.9	12,455
1918	1394	13,036	10.7	14,430

TABLE 15.—PRODUCING OIL-WELLS IN THE UNITED STATES, OCTOBER 31, 1920
(Data from U. S. Geological Survey)

	Producing Oil-wells (Thousands of Wells)	Average Daily Production per Well (Barrels)
Pennsylvania	67.7	0.3
Oklahoma	50.7	6.0
Northwestern Ohio	21.1	0.3
West Virginia	19.5	1.1
Central and Eastern Ohio	18.5	0.8
Illinois	16.8	1.7
Kansas	15.7	6.7
New York	14.0	0.2
California	9.49	32.3
Central and Northern Texas	9.40	22.9
Kentucky	7.80	3.1
Northern Louisiana	2.56	31.6
Indiana	2.40	1.1
Coast Texas	1.70	49.7
Wyoming and Montana	1.00	55.9
Coast Louisiana	0.14	34.6
Colorado	0.07	4.1
Country	258.60	4.9

Oil Acreage.—The acreage in the United States reported by the U. S. Geological Survey as oil-bearing is shown by years from 1913-1918 in Table 14 and Fig. 10. Most of the oil acreage is operated on a royalty basis, only 10.7 per cent of the total being held in fee in 1918. The total acreage classed as oil-bearing in 1918 amounted to 14 million acres, or approximately 22,500 square miles—0.74 per cent of the area of the United States exclusive of Alaska.

Fig. 11.—Number of producing oil wells in the United States on Oct. 31, 1920, by fields; data from U. S. Geological Survey.

Producing Oil-wells.—On October 31, 1920, there were approximately 258,600 producing oil-wells in the United States, with an average daily production of 4.9 barrels per well. The number and average size of the wells in the various fields are shown in Table 15, where conditions may be seen to range from 14,040 wells in New York averaging 0.2 barrel daily to 1000 wells in Wyoming and Montana averaging 55.9 barrels daily. (See also Fig. 11.) In general, the older fields have great numbers of small wells, while the newer fields are characterized by fewer wells of greater flow; there is a relationship also between productivity per well and the price of crude petroleum, since small wells must be pumped at added production costs. Thus in periods of rising prices many small wells, especially in the older fields, are brought into play, only to relapse into inaction when prices fall below their respective economic limits.

The distribution of producing wells on January 1, 1919, more recent data in sufficient detail being unavailable, is shown on a map of the United States in Fig. 12. The relative density of wells in the Appalachian field points to the intensity of exploitation in this region.

The change in the number of producing oil-wells in various states for the period from 1913 to 1920 is shown in Table 16. It is apparent that in most states the number of producing wells is being augmented, which means that new wells are drilled in greater number than old wells become extinct.

New Wells Completed.—The number of new wells completed in the various fields in each year from 1913–1920 is shown in Table 17,

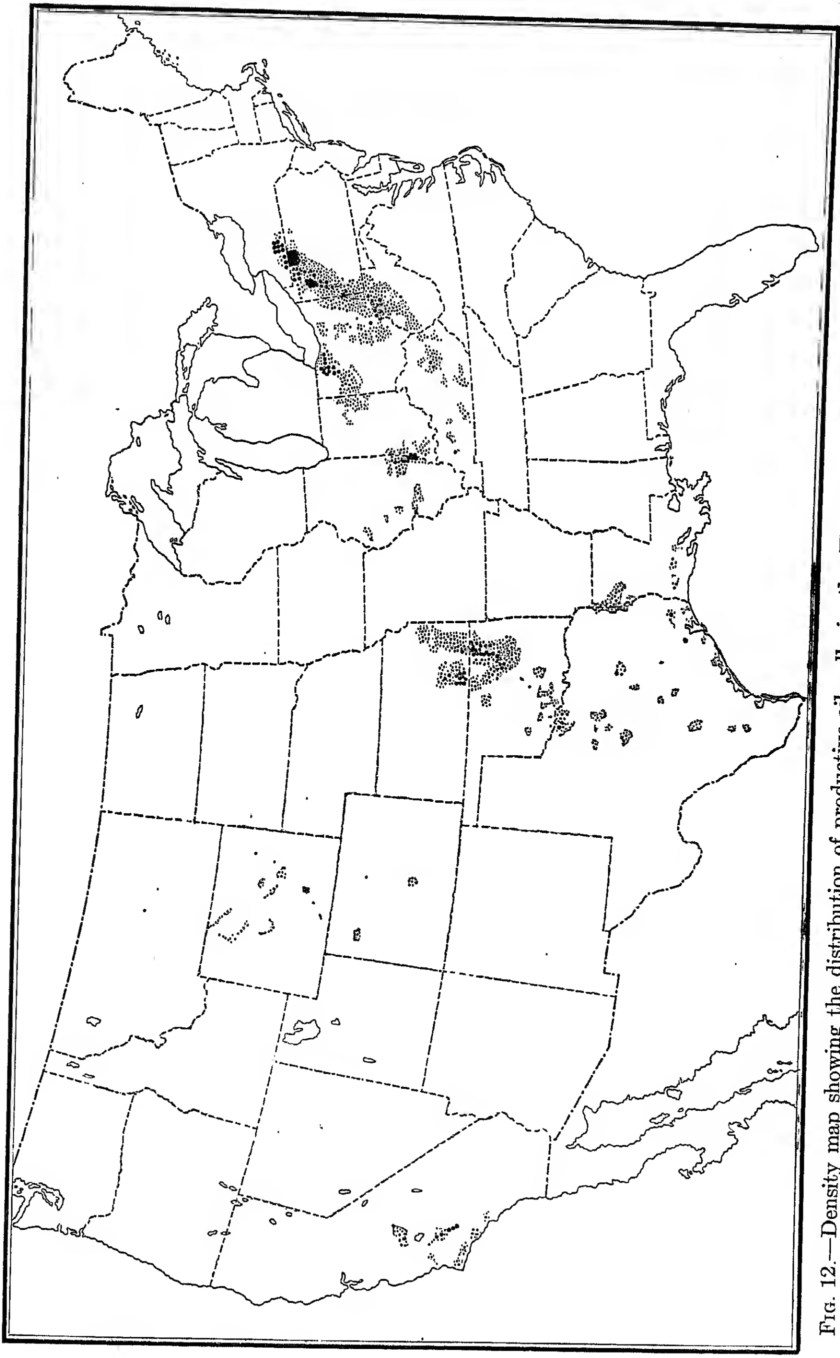


FIG. 12.—Density map showing the distribution of productive oil wells in the United States on Jan. 1, 1919. Density of dots is proportional to number of wells. Data from U. S. Geological Survey.

TABLE 16.—PRODUCING OIL-WELLS IN THE UNITED STATES, 1913–1920, BY STATES

(Data from U. S. Geological Survey)

(In thousands of wells)

	1913*	1914*	1915*	1916*	1917*	1918*	1920†
California	6.82	7.13	7.31	7.78	8.36	8.97	9.49
Colorado	0.09	0.09	0.09	0.09	0.09	0.10	0.07
Illinois	14.1	14.8	15.2	15.8	16.1	16.0	16.8
Indiana	3.81	3.40	2.90	2.53	1.94	1.80	2.40
Kansas	3.05	3.41	3.67	5.84	7.51	8.68	15.7
Kentucky	0.97	1.03	1.06	1.86	2.89	3.62	7.80
Louisiana	0.99	1.18	1.54	1.73	1.89	2.19	2.70
New York	10.7	11.1	11.0	11.2	11.4	11.4	14.0
Ohio	31.2	31.8	30.8	30.8	30.0	30.0	40.0
Oklahoma	24.1	27.8	29.1	31.7	35.1	37.7	50.7
Pennsylvania	55.3	58.3	58.4	58.4	58.9	58.9	67.7
Texas	3.54	3.85	4.33	5.19	6.02	7.13	11.1
West Virginia	14.5	14.9	15.3	15.9	16.2	16.4	19.5
Wyo. and Mont.	0.20	0.26	0.32	0.42	0.72	0.94	1.00
Total	169	179	181	189	197	203	259

* December 31. † October 31.

TABLE 17.—WELLS COMPLETED IN THE UNITED STATES BY FIELDS, 1913–1920

(Data compiled chiefly from Oil and Gas Journal)

	1913	1914	1915	1916	1917	1918	1919	1920
Eastern	7,905	5,909	4,085	6,234	5,435	4,413	5,192	5,682
Lima-Ind.	.....	1,605	452	966	800	693	824	1,057
C. Ohio	.....	768	952	469	582	605	940	1,242
Illinois	.....	1,583	756	1,459	647	397	370	385
Ky.–Tenn.	.....	179	104	1,091	1,651	2,190	3,734	2,888
Kansas	2,174	2,362	1,088	3,637	3,469	4,671	3,442	3,163
Oklahoma	9,131	8,297	4,603	7,730	6,717	8,374	8,196	9,187
N. Texas	761	755	295	576	1,020	1,225	3,564	6,479
N. La.	541	448	476	546	472	533	724	1,163
Gulf	731	564	859	1,113	1,562	1,677	1,238	1,760
Wyoming	.....	.....	74	134	277	248	286	348
California	575	421	240	645	736	589	559	587
Total U. S.	25,582	22,891	13,984	24,620	23,091	25,615	29,069	34,021

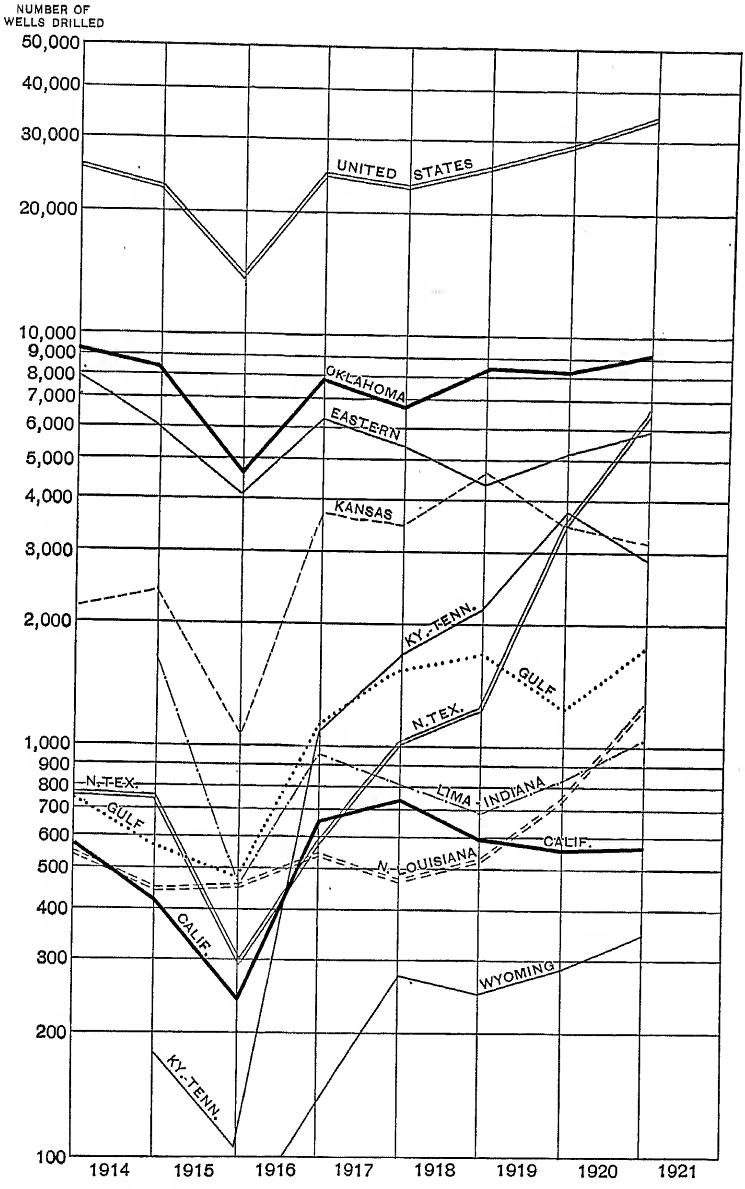


FIG. 13.—Wells completed annually in the United States by fields, 1913–1920. Data from Oil and Gas Journal.

while the data are plotted on a ratio chart [1] in Fig. 13 in order to interpret the trend of this development work. The notable decline in drilling that characterized 1915 in response to the 1914–1915 period of overproduction in the Mid-Continent field is suggestive of the probable course of drilling in 1921, following the 1920 period of overproduction. The marked increase in drilling activity in northern Texas and northern Louisiana during 1919–1920 in particular forms a conspicuous feature of the chart.

Not all wells drilled strike oil, and the numerical relation between new oil-wells and dry holes over a period of years is shown in Table 18 and Fig. 14 for the great Mid-Continent field. In this region, about a

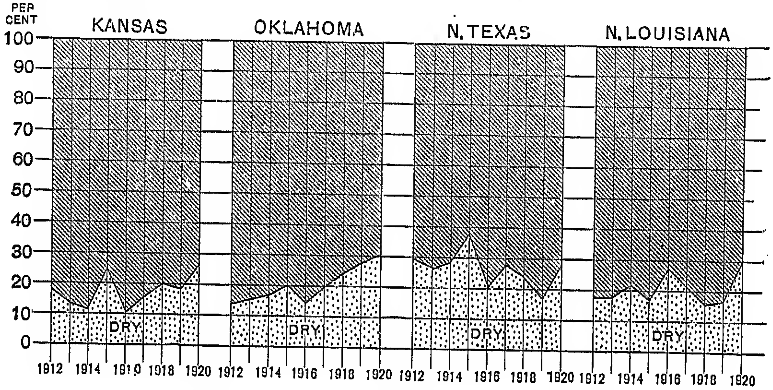


Fig. 14.—Ratio of dry holes to total wells drilled in the Mid-Continent field by years, 1912–1920. After data compiled from Oil and Gas Journal by Bates and Lasky.

quarter of the drilling is usually non-productive. No distinct trend is revealed by the data as to whether drilling in the aggregate is becoming more successful by virtue of the widespread application of geological science, but presumably this latter factor is tending to offset the growing difficulty of locating productive formations as the unknown portion of the reserve is progressively diminished in size.

Relation between Producing Wells and New Wells Completed.—For the period 1910–1920, the ratio of new wells to total producing

[1] The ratio, or semi-logarithmic chart, is used frequently in this book because of its value in analyzing and interpreting economic data. By virtue of the scale, the slopes of the curves are proportional to the percentage changes, and comparisons between separate curves on the same chart may accurately be made. For a detailed description of the ratio chart consult Irving Fisher, The "Ratio" Chart for Plotting Statistics; and J. A. Field, Some Advantages of the Logarithmic Scale in Statistical Diagrams, Journal of Political Economy, vol. 25, 1917, pp. 805–841.

TABLE 18.—WELLS DRILLED IN MID-CONTINENT FIELD, BY STATES, 1912–1920*

	Wells Drilled				Percentage Dry Wells	Initial Production	
	Oil	Dry	Gas	Total		Total Barrels	Average per Well
KANSAS:							
1912.........	536	160	253	949	16.8	7,245	13.5
1913.........	1422	260	334	2016	12.9	22,467	15.8
1914.........	1753	270	317	2340	11.5	18,932	10.8
1915.........	610	147	331	1088	24.1	11,319	18.6
1916.........	3142	370	112	3624	10.2	248,846	79.2
1917.........	2712	538	177	3427	15.7	319,093	117.6
1918.........	3463	935	273	4671	20.0	342,853	99.0
1919.........	2638	630	174	3442	18.3	172,479	65.0
1920.........	2327	690	147	3164	26.4	181,845	78.0
OKLAHOMA:							
1912.........	4712	843	438	5993	14.1	228,886	48.6
1913.........	6965	1308	578	8851	15.3	334,050	48.0
1914.........	6410	1343	539	8292	16.2	976,244	152.3
1915.........	3397	885	342	4624	19.1	1,036,170	305.0
1916.........	6086	1120	377	7583	14.8	521,895	85.8
1917.........	5027	1360	410	6797	20.0	365,314	72.[illegible]
1918.........	5529	2071	754	8354	24.8	372,558	67
1919.........	5203	2278	715	8196	27.8	487,939	93
1920.........	6303	2036	758	9097	30.8	773,900	122.8
TEXAS (North):							
1912.........	299	124	11	434	28.6	28,213	94.3
1913.........	581	208	10	799	26.0	57,435	98.9
1914.........	497	221	26	744	29.7	25,003	50.3
1915.........	307	198	23	528	37.5	52,663	171.5
1916.........	500	145	38	683	21.2	49,728	99.5
1917.........	728	290	23	1041	27.9	51,128	70.2
1918.........	896	285	10	1191	23.9	148,362	165.5
1919.........	2921	598	45	3564	16.8	1,736,712	594.9
1920.........	4590	1686	233	6509	29.5	1,046,427	228.2
LOUISIANA (North)							
1912.........	239	62	52	353	17.6	84,098	359.9
1913.........	356	93	70	519	17.9	151,955	426.8
1914.........	302	94	52	448	20.9	102,193	338.4
1915.........	349	89	26	464	17.0	198,116	567.7
1916.........	324	141	55	520	27.1	54,871	169.4
1917.........	302	99	56	457	21.7	59,272	196.3
1918.........	391	85	57	533	15.9	173,460	443.6
1919.........	518	119	67	704	16.9	453,669	875.7
1920.........	873	242	131	1246	30.0	640,853	735.0

* From compilation by Bates and Lasky from Oil and Gas Journal.

wells in the United States has averaged about 12 per cent; that is, roughly 1 well has been drilled each year for every 8 wells producing. The trend of the number of new wells in comparison with the old wells is shown for a number of years in Table 19.

TABLE 19.—PRODUCING WELLS AND NEW WELLS COMPLETED IN THE UNITED STATES BY YEARS, 1908–1920

(Data from U. S. Geological Survey)

	Producing Wells, Dec. 31 (Thousands of Wells)	Average Daily Production per Well (Approximate) (Barrels)	Wells Completed During Year (Thousands of Wells)
1908	142	...	16.9
1909	147	3.3	18.3
1910	148	3.7	14.9
1911	153	3.6	13.8
1912	158	3.8	17.2
1913	169	3.9	25.6
1914	179	4.1	22.9
1915	181	4.5	14.0
1916	189	4.4	24.6
1917	197	4.5	23.1
1918	203	4.7	25.6
1919	...	...	29.0
1920	259*	4.9*	34.0

* October 31.

Fig. 15 illustrates how the mounting production of crude petroleum has been dependent upon an increasing campaign of drilling and a growing number of producing wells. The general conformance in trend between the three curves appearing in Fig. 15 should not escape attention.

The output of petroleum depends upon the total yield from old wells plus the production of new wells, each of the two components of the total being a function of the number of wells and their average productivity. Since wells display individually a declining production, the composite output can be maintained or increased only by adding new production in sufficient degree to compensate for the falling off in old production. For example, the average decline of production in the Mid-Continent field is 17 per cent of the preceding year.[1]

[1] See Bates and Lasky, Statistical Review of Mid-Continent Field, National Petroleum News, March 30, 1921, p. 71.

In 1919 this field produced 197 million barrels; if no new wells had been drilled during 1920, the production in 1920 would have fallen to 164 million barrels. In 1920, however, 14,000 oil-wells were drilled in this field and the total output of the field was 249 million barrels. Thus new production to the extent of 85 million barrels was contributed by the 14,000 new wells drilled during the year, or approximately 6000 barrels for each new well. The average initial daily production of the new wells in 1920 was 188 barrels; assuming an even rate of drilling throughout the year, the new wells averaged six months' performance each. Consequently, the average output

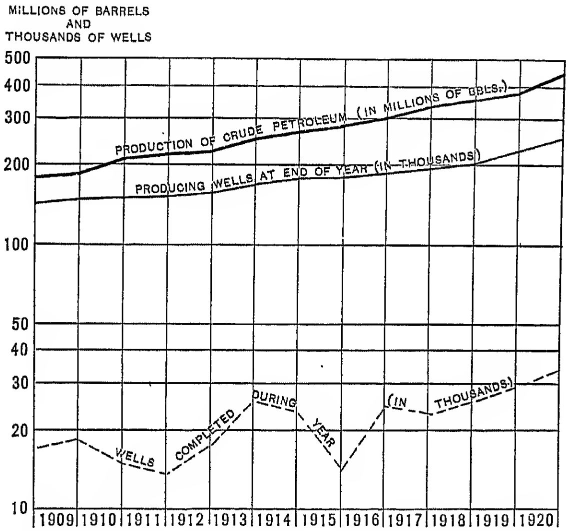


Fig. 15.—Comparison of producing wells, new wells, and production of crude petroleum in the United States by years, 1908–1920; data from U. S. Geological Survey.

per new well for the year would have been 34,300 barrels ($188 \times 365 \div 2$), if output had been sustained at the initial rate. The factor of decline, however, brought the performance down to 6000 barrels, a discount of 83 per cent.

New production is not reported directly by the oil journals or other statistical sources, but may be calculated from a knowledge of the wells drilled and their average initial daily production, if the average annual rate of decline is also known. The trend of the number of wells drilled and their initial unit output in the Mid-Continent field is plotted on a ratio scale in Fig. 16 from data given in Table 18. The effects of the development of the Cushing pool in 1914–1915, and of the bringing in of large wells in Oklahoma, North

Texas, and Louisiana in 1919 are strikingly shown. The fact that no new pools of large size were brought into production during 1920 resulted in a reduction in the average initial production per well from 253 barrels in 1919 to 188 barrels in 1920, as clearly shown in the chart. This decline in unit production, however, was compensated by the greater number of new wells brought in, so that new

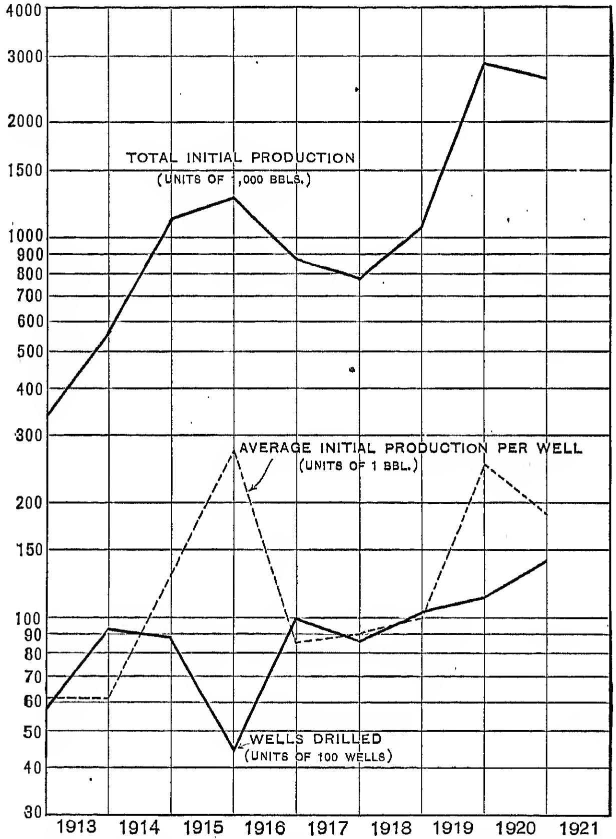


Fig. 16.—Trend of drilling activity in the Mid-Continent field by years, 1913–1920.

production mounted from 48 million barrels in 1919 to 85 million in 1920.

Relation between Production and New Wells Completed.—The dependence of production upon the bringing in of new wells is shown for the Mid-Continent field in Fig. 17, in which the volume of production is plotted on a ratio scale against the number of new wells by months for the period of 1917–1921. It is immediately

apparent that the upward trend of the production curve is supported by a corresponding trend for the number of new wells. The latter curve, however, shows a marked seasonal variation, reaching a maximum in the summer months and declining during the winter months. This seasonal characteristic of drilling has a systematic, but deferred and modified effect upon production, which shows a less accentuated response to the season. In addition, the number of

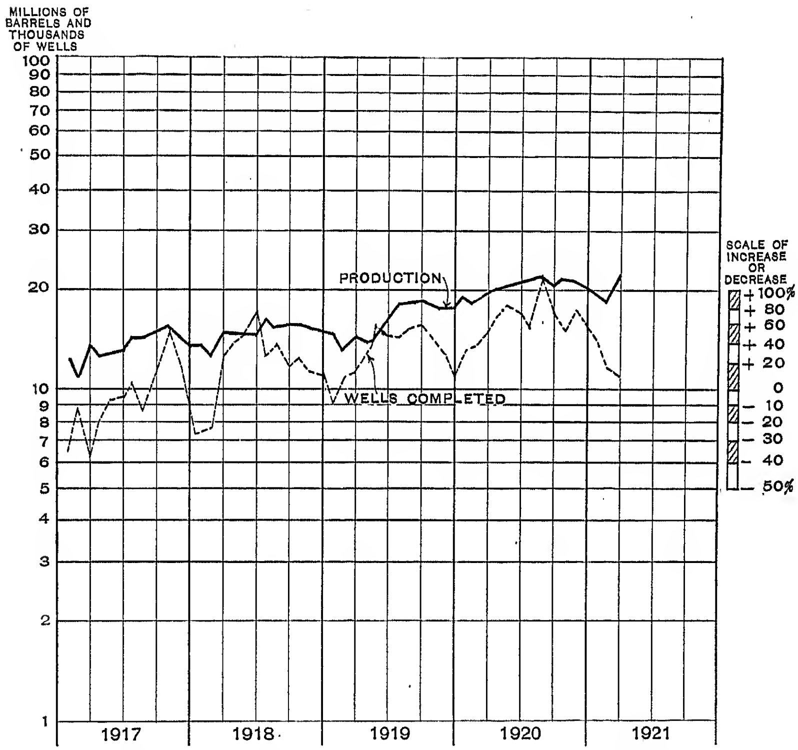


FIG. 17.—Relation of wells completed to production in the Mid-Continent Field by months, 1917–1920.

completions is influenced by general economic conditions, though to a less degree than might be expected, as illustrated by the relatively moderate decline in new completions during the industrial depression of 1920–21, the recession shown being little more than the normal seasonal decline. The competitive factor here is so powerful that drilling activity responds only with reluctance to depressing influences.

Decline Curves.—The importance of drilling for the maintenance of a mounting production of petroleum is exemplified by the declining

production invariably displayed by a single well or group of wells, if unsupported by the bringing in of new wells. The typical course of an oil-producing property is shown in Fig. 18, where the production of a group of actual wells in Oklahoma is plotted on a ratio scale. By fitting a straight line to the curve and determining its slope, it becomes apparent that the rate of decline averaged 40 per cent a year for the ten-year period under observation. The production of the country is merely a composite of a great number of individual properties, each yielding decline curves after drilling is completed.

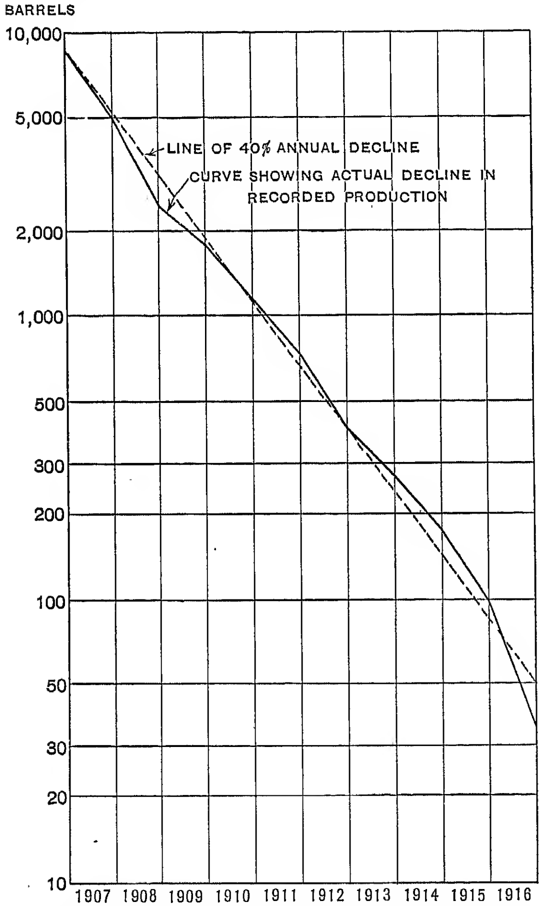


FIG. 18.—Decline in output of a typical Oklahoma property over a ten-year period; data from Arnold and Darnell.

After a regional group of properties, or field, reaches its maximum production, it enters upon a long course of decline, as may be seen in Fig. 21, page 55. The entrance upon the decline comes when the production of new wells fails to make up for the decrease of the old. Although this situation has overtaken a number of fields, it has not yet dominated the aggregate of fields, although it soon may be expected to do so. The decline curve of the country as a whole can scarcely be predicated on the basis of the decline curves of the older fields, since changing technology and rising price may be expected to considerably modify the decline curves we know from experience.

Estimating Future Production by Decline Curves.—Many thousand decline curves have been plotted by petroleum engineers, and afford a mass of recorded experience indicating that decline curves are notably symmetrical. It has also been proved by experience that such curves "can be extended beyond the actual period of production by continuing the curves in accordance with their symmetry and that such projections, if skillfully made, provide fairly trustworthy estimates of the future production of the well."[1] The technique of employing production data for estimating oil reserves and the rate at which they may be recovered has been skillfully developed, and the valuation of oil properties, with due allowance for depreciation and depletion, has been made a quantitative procedure. The requirements of the U. S. Treasury in regard to the taxation of oil properties have greatly stimulated the accuracy of appraisals, since the rulings of the Treasury have been carefully drawn up on a scientific basis by a corps of able petroleum geologists and engineers, and carelessly prepared tax returns are not accepted.

Conclusion.—Petroleum exploration and drilling are more or less amenable to the ordinary accelerating or retarding factors that affect industrial operations in general; but the output of crude petroleum, under the impetus of a small-unit competition that cannot afford to let up substantially under any circumstances, proceeds without regard to outside pressure. In consequence, the production of crude petroleum responds quite laggardly to changed conditions, being affected mainly in its exploration and drilling stage several months removed from production proper. The necessity for an ever-expanding campaign of drilling to replace the declining output of old wells places a cumulative burden upon oil-field exploitation which cannot be perpetually borne. Sooner or later new wells in adequacy cannot be found and the production of the country as a whole will inevitably display the decline that inexorably affects the well, the property, the pool, and the field; a waning output will supervene and the production curve of the country will describe a declining course, gentler in slope perhaps than the composite curves we now know from experience, forcing into prominence far-reaching changes in technology and economic procedure, profoundly affecting the composition and structure of the petroleum industry.

[1] Arnold, Darnell, and others, Manual for the Oil and Gas Industry under the Revenue Act of 1918, N. Y., 1920, p. 85. See also Beal, The Decline and Ultimate Production of Oil-wells, with Notes on the Valuation of Oil Properties, U. S. Bureau of Mines, Bull. 117, 1919.

CHAPTER IV

TREND OF OIL PRODUCTION

THE production of crude petroleum is strongly influenced by the geological conditions under which it occurs and the economic circumstances under which it is dominantly exploited. Its liquidity and occurrence under pressure, on the one hand, lead to prolific outflow when once productive deposits are tapped; while, on the other, its development from surface properties that divide the underground mineral unit into many arbitrary portions, institutes a competitive extraction that does not decline materially in the face of overproduction. These circumstances, which are unique with petroleum, coupled with the pioneer spirit that has been present in this country, are responsible for a mounting output remarkable for its rate of increase. Moreover, because of its ready adaptability to service, the quantity produced has always been able to force room for itself in low-use directions after the higher demands for its products were satisfied. To a considerable degree, therefore, the yield of crude petroleum has been promoted by factors forcing the output in advance of fundamental requirements, which, in turn, has stimulated a rigorous extension of markets and uses, but with surplus always in evidence to find an outlet as fuel. In short, supply has shaped demand.

The Mounting Course of Production.—The economic characteristics of petroleum just outlined serve to explain the remarkable rise of production in this country from less than one million barrels in 1860 to 443 million barrels in 1920. Fig. 19 depicts on a ratio scale the steep slope of the production curve over the past sixty years, from which it is apparent that the output has roughly doubled every ten years. A closer analysis of this curve reveals the fact that its trend from 1860–1880 averages 13 per cent a year; from 1880–1900, 6 per cent annually; and from 1900–1920, 10 per cent yearly.[1] The smoothness of the curve during the past decade, as compared with previous decades or production curves of other materials, is

[1] Determined graphically by fitting straight lines by inspection to the three portions of the curve.

worthy of note as reflecting close conformity to a geometric progression.

Comparison with Growth of Country.—The production of crude petroleum has, of course, increased far more rapidly than population,

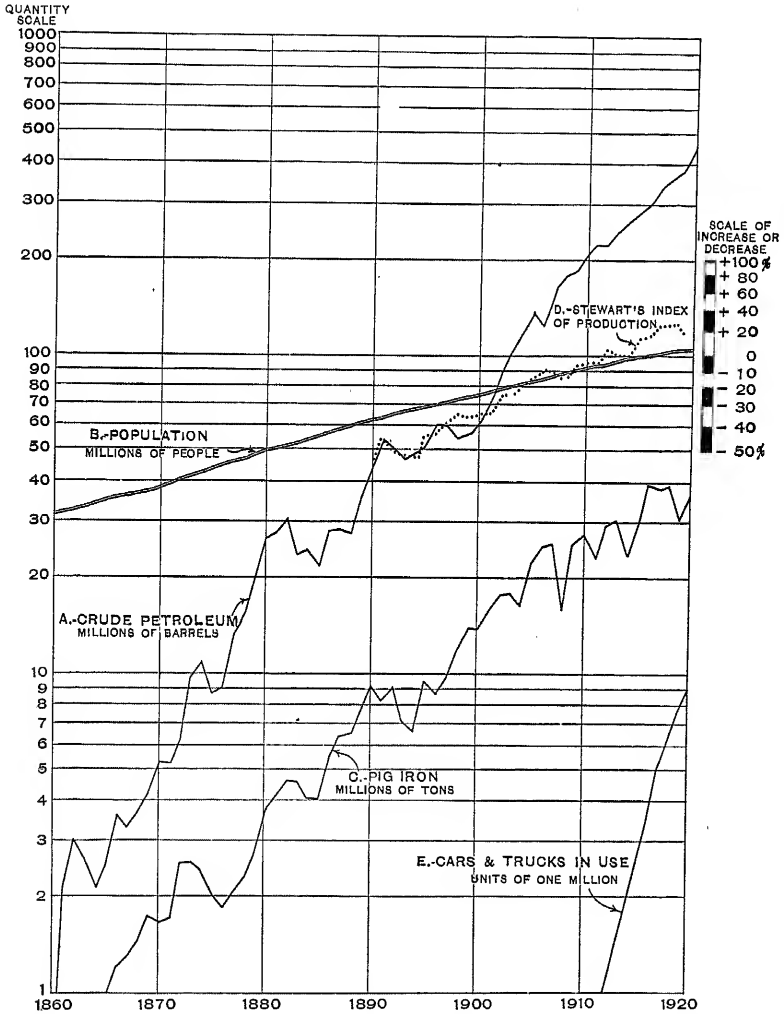


Fig. 19.—Growth in the production of crude petroleum in the United States, by years, 1860–1920, compared with the output of pig iron, increase in population, and other indices.

as illustrated by Fig. 19 which measures the rate of growth of each. In 1902 the per capita production of petroleum was 1 barrel, while by 1920 this ratio had increased to 4.3 barrels. In this respect

petroleum shares distinction with most of the other minerals, as contrasted with agricultural products which display rates of growth roughly parallel to the population increase.

Of greater significance, however, is a comparison with the industrial growth of the country. Such a comparison is afforded by plotting pig iron production against crude petroleum output, as given in Fig. 19. An extensive investigation of the physical production of the United States by E. E. Day of the Harvard University Committee on Economic Research has shown that pig iron production is the best single index of manufacturing activity available and in fact shows a remarkably close conformance with the composite index calculated from a wide range of production data.[1] It is apparent from Fig. 19 that the curves for crude petroleum and pig iron show a fairly parallel development for the period 1860–1900, but from 1900 to 1920 petroleum displays the more rapid increase. It was during the latter period, of course, that the great oil-fields of the Mid-Continent, Gulf Coast, and California regions came into flush production, and the output of petroleum in consequence went ahead of the normal industrial growth of the country(see Fig. 22).

An index of the growth in the country's productivity as prepared by Walter W. Stewart is introduced into Fig. 19 to afford further comparison of the degree to which petroleum output has forged ahead of the average production of all commodities in the past twenty years. The angle between the two curves is a measure of this divergence and is strikingly great; the conformance between the two curves from 1890 to 1900 should also be noted.

The rise of automotive transportation, which has largely taken place since 1912, has profoundly affected the oil industry, and the relationship between crude oil production and automotive registrations is quantitatively shown by a comparison of Curves A and E in Fig. 19. The steepness of Curve E is notable, but is the characteristic slope of industrial youth.

Relation to Other Countries.—For many years the United States has been producing around two-thirds of the petroleum brought to the surface in the world. Her two largest competitors in production have been Russia and Mexico, the three countries combined turning out around 90 per cent of the world's supply. The trend of production in these leading countries is presented in Fig. 20, where the slopes of the lines are proportional to the percentage changes and the curves are consequently directly comparable. The marked parallelism between Curves A and B is readily understandable in view of the dominant contribution to the world's supply made by

[1] The Review of Economic Statistics, Dec., 1920, p. 367.

the United States. Production in Russia (Curve C) shows a rapid development in 1880–1890, a sharp but less accentuated rise between 1890 and 1900, exceeding the output of the United States in 1898 and the three years subsequent, and a fluctuating but somewhat declining course during the two decades of the present century, with an abrupt decline in 1917.

Mexico (Curve D) displays a phenomenal growth in production from approximately 1 million barrels in 1906 to 163 million barrels in 1920, with a tendency throughout the past decade to increase at the rate of about 25 per cent a year. The curve for Mexican production is characteristically that of a youthful, flush producer, with somewhat greater steepness than normal because of the unusually large wells in that country.

The data upon which Fig. 20 is based, together with production figures for the less important countries, are presented in Table 20.

Trend of Production by Fields.—The production of the United States as a whole is a composite of many individual fields, some young and growing in output, others mature and stable, still others old and waning in vigor. It is necessary, therefore, to bring the components of the country's supply into comparison, in order to analyze their relationships one to another and to the whole. For this purpose, the productions of the various oil-fields since 1900 are plotted on a ratio scale in Fig. 21, which reflects the trend of each contributor. The chart is somewhat confusing because of the necessarily large number of curves appearing upon it, but the complex of lines reveals unmistakably the tendency of all fields to spring quickly into prominence, to maintain themselves with fluctuations for a period, and then to enter upon a long decline. The curve for Illinois is typical and represents, with due qualifications, the course to be followed by the immature fields, such as North and Central Texas and the Rocky Mountain, of whose trend curves only the early, youthful portions appear in the chart. Study of Fig. 21 will emphasize the degree to which the maintenance of the total output is dependent upon the coming in of a *growing* number of new fields, as the older fields in increasing numbers enter upon a waning course. It is obvious, and indeed susceptible of rigorous mathematical proof, that a progression of this kind must eventually reach a point where the declining functions will dominate and force the composite curve downward.

The significance of Fig. 21 can scarcely be over-stressed. The semi-logarithmic scale upon which the data are plotted yields a type of curve that truly reflects a picture of all the complex factors—physical, chemical, geological, economic, and psychological—that enter into production. The curves are not merely graphic expressions

TABLE 20.—WORLD'S PRODUCTION OF CRUDE PETROLEUM, 1901–1920, BY COUNTRIES. DATA FOR 1901–1919 FROM U. S. GEOLOGICAL SURVEY. 1920 DATA FROM AMERICAN PETROLEUM INSTITUTE

(In millions of barrels of 42 U. S. gallons)

Year	United States	Mexico	Russia	Dutch East Indies	Rumania	India	Persia	Galicia	Peru	Japan and Formosa	Trinidad	Egypt	Argentina	Germany	Venezuela	Canada	Other Countries	World
1901	69.4	0.01	85.2	4.01	1.68	1.43	.....	3.25	0.27	1.11	.....	.....	.....	0.31	.....	0.76	0.02	167
1902	88.8	0.04	80.5	2.43	2.06	1.62	.....	4.14	0.29	1.19	.....	.....	.....	0.35	.....	0.53	0.03	182
1903	100	0.08	75 6	5.77	2.76	2.51	.....	5.23	0.28	1.21	.....	.....	.....	0.45	.....	0.49	0.04	195
1904	117	0.13	78.5	6.51	3.60	3.39	.....	5.95	0.35	1.42	.....	.....	.....	0.64	.....	0.55	0.04	218
1905	135	0.25	55.0	7.85	4.42	4.14	.....	5.77	0.45	1.47	.....	.....	.....	0.56	.....	0.63	0.03	215
1906	126	0.50	58.9	8.18	6.38	4.02	.....	5.47	0.54	1.71	.....	.....	.....	0.58	.....	0.57	0.03	213
1907	166	1.01	61.9	9.98	8.12	4.34	.....	8.46	0.76	2.00	.....	.....	.....	0.76	.....	0.79	0.03	264
1908	179	3.93	62.2	10.3	8.25	5.05	.....	12.6	1.01	2.07	.....	.....	0.01	1.01	.....	0.53	0.03	286
1909	183	2.71	66.0	11.0	9.33	6.68	.....	14.9	1.32	1.89	0.06	.....	0.02	1.02	.....	0.42	0.02	299
1910	210	3.63	70.3	11.0	9.72	6.14	.....	12.7	1.33	1.93	0.14	.....	0.02	1.03	.....	0.32	0.02	328
1911	220	12.6	66.2	12.2	11.1	6.45	.....	10.5	1.37	1.66	0.29	.....	0.01	1.02	.....	0.29	0.02	344
1912	223	16.6	68.0	10.8	13.0	7.12	.....	8.54	1.75	1.67	0.44	0.21	0.05	1.03	.....	0.24	0.02	352
1913	248	25.7	62.8	11.2	13.6	7.93	.....	7.82	2.13	1.94	0.50	0.09	0.13	1.00	.....	0.23	0.02	384
1914	266	26.2	67.0	11.8	12.8	7.41	.....	5.03	1.92	2.74	0.64	0.78	0.28	1.00	.....	0.21	0.02	404
1915	281	32.9	68.5	12.4	12.0	8.20	.....	4.16	2.49	3.12	0.75	0.26	0.52	1.00	.....	0.22	0.01	428
1916	301	39.8	72.8	13.2	8.95	8.49	.....	6.46	2.55	3.00	0.93	0.41	0.80	1.00	.....	0.20	0.03	459
1917	335	55.3	70.0	12.9	3.72	8.08	6.86	5.97	2.53	2.88	1.60	1.01	1.14	1.00	0.13	0.21	0.02	509
1918	356	63.8	40.5	13.3	8.73	8.00	7.20	5.59	2.54	2.45	2.08	2.08	1.32	0.71	0.19	0.30	.....	515
1919	378	87.1	25.5	15.4	6.61	8.74	6.41	6.05	2.62	2.18	1.84	1.50	1.18	0.23	0.43	0.24	1.14	545
1920	443	160	30.0	16.0	7.41	8.50	6.60	6.00	2.79	2.21	1.63	1.09	1.37	0.22	0.50	0.22	0.70	688

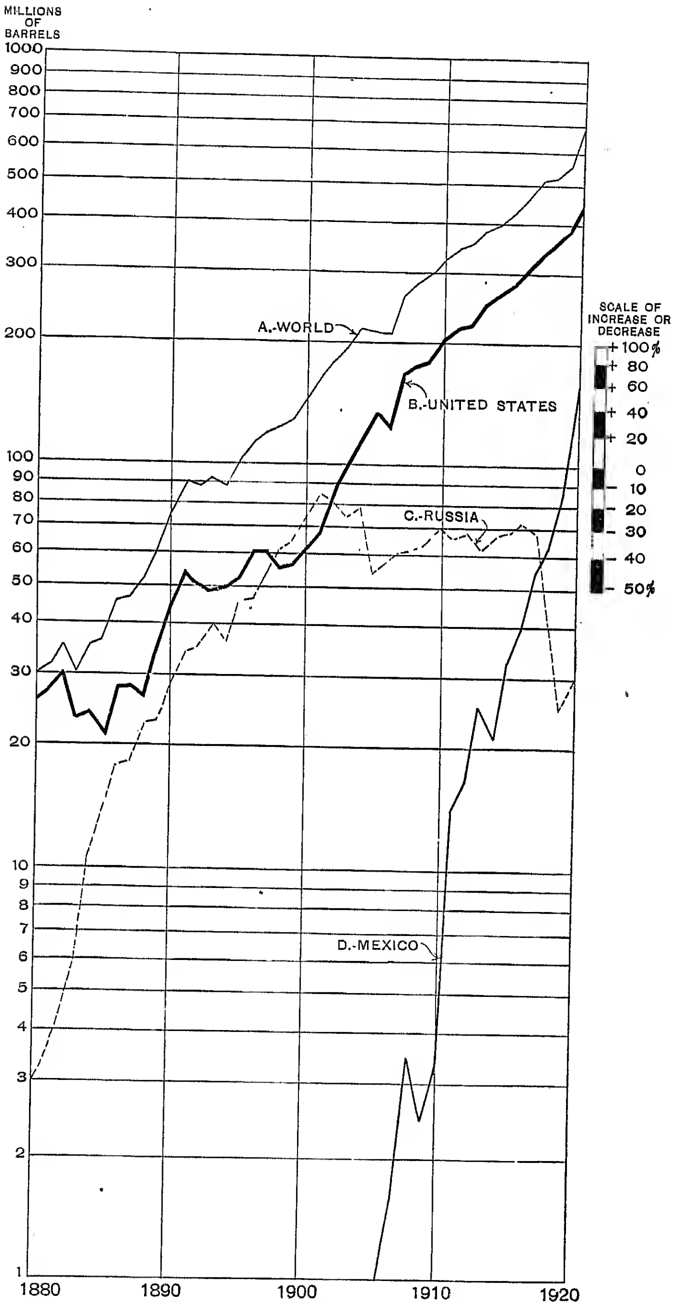


FIG. 20.—The annual production of crude petroleum in the United States compared with other leading countries, 1880–1920.

TABLE 21.—PRODUCTION OF PETROLEUM IN THE UNITED STATES BY STATES, 1901–1920

States are arranged in order of the date of their initial production; output under 5000 barrels not shown; data from U. S. Geological Survey

(In millions of barrels)

Year	Penn. and N. Y.	Ohio	W. Va.	Calif.	Ky. and Tenn.	Colo.	Indiana	Illinois	Kansas	Texas	Mo.	Okla.	Wyo.	La.	Mont.	United States
1901	13.8	21.6	14.2	8.79	0.14	0.46	5.76	....	0.18	4.39	....	....	....	....	...	69.4
1902	13.2	21.0	13.5	14.0	0.19	0.40	7.48	....	0.33	18.1	....	0.04	....	0.55	...	88.8
1903	12.5	20.5	12.9	24.4	0.55	0.48	9.19	....	0.93	18.0	....	0.14	....	0.92	...	100
1904	12.2	18.9	12.6	29.6	1.00	0.50	11.3	....	4.25	22.2	....	1.37	....	2.96	...	117
1905	11.6	16.3	11.6	33.4	1.22	0.38	11.0	0.18	12.0*	28.1	....	*	....	8.91	...	135
1906	11.5	14.8	10.1	33.1	1.21	0.33	7.67	4.40	21.7*	12.6	....	*	....	9.08	...	126
1907	11.2	12.2	9.10	39.7	0.82	0.33	5.13	24.3	2.41	12.3	....	43.5	....	5.00	...	166
1908	10.6	10.9	9.52	44.9	0.73	0.38	3.28	33.7	1.80	11.2	....	45.8	0.02	5.79	...	179
1909	10.4	10.6	10.7	55.5	0.64	0.31	2.30	30.9	1.26	9.53	....	47.9	0.02	3.06	...	183
1910	9.85	9.92	11.8	73.0	0.47	0.24	2.16	33.1	1.13	8.90	....	52.0	0.12	6.84	...	210
1911	9.20	8.82	9.80	81.1	0.47	0.23	1.70	31.3	1.28	9.53	....	56.1	0.19	10.7	...	220
1912	8.71	8.97	12.1	87.3	0.48	0.21	0.97	28.6	1.59	11.7	....	51.4	1.57	9.26	...	223
1913	8.87	8.78	11.6	97.8	0.52	0.19	0.96	23.9	2.38	15.0	0.01	63.6	2.41	12.5	...	248
1914	9.11	8.54	9.68	99.8	0.50	0.22	1.34	21.9	3.10	20.1	0.01	73.6	3.56	14.3	...	266
1915	8.73	7.83	9.26	86.6	0.44	0.21	0.88	19.0	2.82	24.9	0.01	97.9	4.25	18.2		281
1916	8.47	7.74	8.73	91.0	1.20	0.20	0.77	17.7	8.74	27.6	0.01	107	6.23	15.2	0.04	301
1917	8.61	7.75	8.38	93.9	3.10	0.12	0.76	15.8	36.5	32.4	....	108	8.98	11.4	0.10	335
1918	8.22	7.29	7.87	97.5	4.38	0.14	0.88	13.4	45.5	38.8	....	103	12.6	16.0	0.07	356
1919	9.44	8.24	9.03	101	5.03	0.24	0.93	12.4	34.8	85.3	....	81.1	13.3	16.3	...	378
1920	8.36	7.41	8.17	106	8.69	0.11	0.93	10.8	38.5	96.0	....	106	17.1	35.6	0.34	443

* Includes Oklahoma in 1905 and 1906.

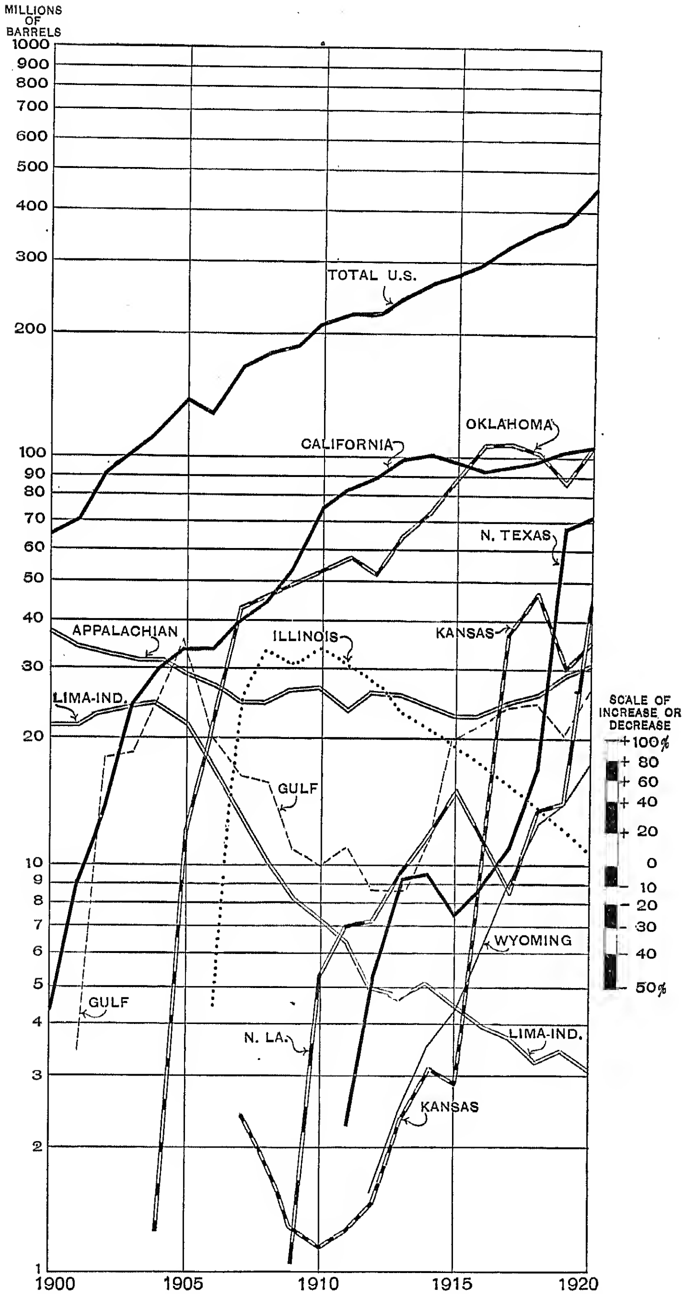


Fig. 21.—Trend of petroleum production in the United States, 1900–1920, by fields.

of statistics; they are visualizations of economic forces; and while these forces cannot always be resolved into their components, they can be observed, measured, weighed against one another, and with due precaution projected ahead.

Production data by states and by fields for a number of years past are given in Tables 21 and 22.

TABLE 22.—PETROLEUM PRODUCED IN THE UNITED STATES, 1913–1920, BY FIELDS

Data from U. S. Geological Survey

Year	Appalachian		Lima-Indiana		Illinois		Mid-Continent		Gulf		Rocky Mts.		California		United States	
	Millions of Barrels	Index Nos.	Millions of Barrels	Index Nos.	Millions of Barrels	Index Nos.	Millions of Barrels	Index Nos.	Millions of Barrels	Index Nos.	Millions of Barrels	Index Nos.	Millions of Barrels	Index Nos.	Millions of Barrels	Index Nos.
1913	25.9	100	4.77	100	23.9	100	84.9	100	8.54	100	2.60	100	97.8	100	248	100
1914	24.1	93	5.06	106	21.9	92	98.0	115	13.1	153	3.78	145	99.8	102	266	107
1915	22.9	88	4.27	90	19.0	80	123	145	20.6	241	4.45	171	86.6	89	281	113
1916	23.0	89	5.06	106	17.7	74	137	161	21.8	256	6.48	249	91.0	93	301	121
1917	24.9	96	4.27	90	15.8	66	164	193	24.3	285	9.20	354	93.9	96	335	135
1918	25.4	98	3.91	82	13.4	56	179	211	24.2	284	12.8	492	97.5	100	356	144
1919	29.2	115	3.44	72	12.4	52	197	232	20.6	241	13.6	523	102	104	378	152
1920	30.5	118	3.06	64	10.8	45	249	294	26.8	314	17.5	673	106	108	443	178

Composite Character of Production.—The composition of the production curve for the whole country is interpreted in a different manner in Fig. 22, in which the yields of the various fields are superimposed on a natural scale. This chart clearly indicates the wedge-like character of the growth—how a mounting production becomes increasingly dependent upon the development of new fields. It also stresses the dominant position held by Oklahoma and California and points to the great number of smaller contributors that must be found to compensate for the decline of these major fields. It should be observed, moreover, that Oklahoma started downward in 1919 only to be temporarily revived in 1920 by the sharp rise in crude oil prices that came in the first quarter of that year, and that California is rapidly approaching its peak. The important contribution made by North and Central Texas in 1919–1920 should not escape attention nor should the fact that this field has already seen its best days. Fig. 22 may be profitably examined in conjunction with Fig. 21 since the two present complementary analyses of the trend of production that may serve as the basis of generalizations as to the future.

Figs. 21 and 22 show clearly the marked stimulation in output that came in 1920 under the influence of the price advance. While the extent of this increase in output is an encouraging indication that there is still considerable resilience in the situation, it should be remembered that the cost was a proportionately greater advance in price, and there is obviously a limit to increases gained in this manner. (See Chapter 18.)

On the whole, Figs. 21 and 22 indicate that production in the United States is fast approaching its limit, and there is much evidence to suggest that 1921 will register the maximum rate of output

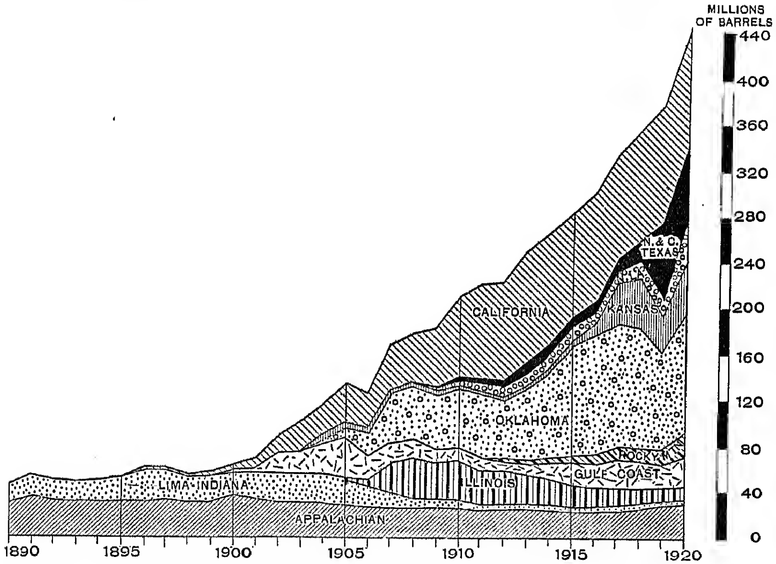


FIG. 22.—Production of crude petroleum in the United States by years, 1890–1920, showing the relative importance of the contributions made by the individual fields.

that this country will enjoy. It should be observed that this deduction is based upon a study of production curves, that is to say, is the result of mathematical analysis, and is not predicated upon estimates of the size of the unmined supply. The apparently limited quantity of petroleum still underground, however, offers additional and corroborative evidence of our proximity to the peak of production in the United States.

Comparative Importance of Fields.—The relative importance of the major producing fields in the United States is shown in Fig. 23, where the dominance of the Mid-Continent and California production is outstanding. The main advance in the country's output

in 1919–1920 is readily seen to lie in the increased productivity of the Mid-Continent field, comprising Oklahoma-Kansas, North and Central Texas, and North Louisiana.

The relative importance of the two major fields is shown in percentage form in the table following:

TABLE 23.—PERCENTAGE OF COUNTRY'S TOTAL OUTPUT OF CRUDE PETROLEUM CONTRIBUTED BY THE MID-CONTINENT AND CALIFORNIA FIELDS, 1913–1920

Year	Mid-Continent (Okla.-Kans., N. and C. Texas, N. La.) Per Cent	California Per Cent	Others, Per Cent	United States, Per Cent
1913	34	39	27	100
1914	37	38	25	100
1915	44	31	25	100
1916	46	30	24	100
1917	49	28	23	100
1918	50	27	23	100
1919	52	27	21	100
1920	56	24	20	100

The Widening Gap between Production and Consumption.— While the production of crude petroleum in the United States has been growing at a rapid rate (see Fig. 19 and Table 22), the consumption of crude petroleum, since 1915 at least, has been increasing still more rapidly, as shown by the following series of index numbers:

TABLE 24.—COMPARISON OF DOMESTIC PRODUCTION AND CONSUMPTION OF CRUDE PETROLEUM, IN PERCENTAGES OF THE FIGURES IN 1913

(Figures for 1913 = 100)

Year	Production	Consumption
1913	100	100
1914	107	100
1915	113	105
1916	121	122
1917	135	145
1918	144	158
1919	152	161
1920	178	204

It is thus seen that from 1913–1920 domestic production increased 78 per cent, while during the same period consumption advanced 104 per cent. The discrepancy was made possible by the growing imports from Mexico, as will appear from examination of Table 25, which shows also the method employed in calculating consumption.

The monthly trend of supply and demand for the period 1917–1920 is shown in comparative form in Fig. 24, which represents an interpretation of the current situation. Annual data show the broad features, but in order to appraise the fluctuations within the year, recourse must be had to monthly statistics. The curves appearing in Fig. 24 depict the economic forces at work, and should be looked at as a moving picture of what is transpiring. The semi-logarithmic scale upon which the data are plotted reduces the fluctuations to a percentage basis, thus revealing the trends, permitting accurate comparisons to be made, and interpreting the change in terms of their economic significance.

In view of the general slowing down in industrial activity during 1920, it is interesting to observe the increasing production throughout the year, together with the sharply mounting imports. These conditions alone were shaping up for a temporary overproduction, which required

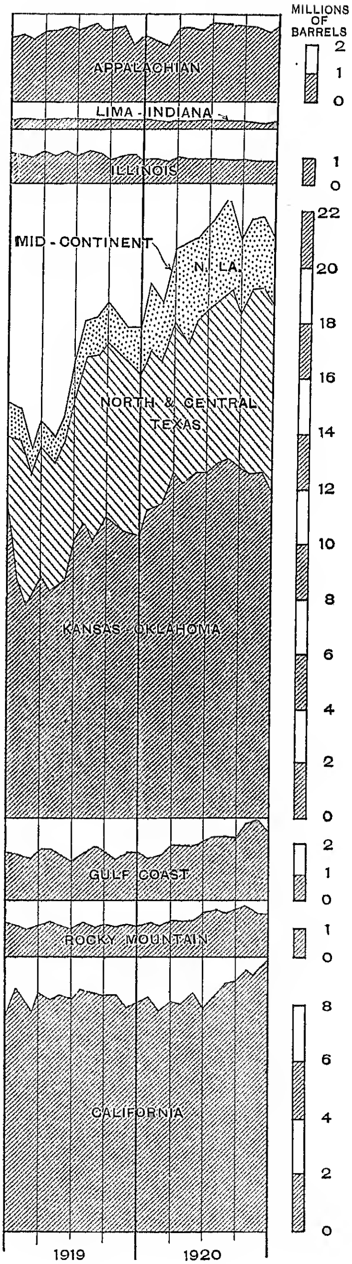


FIG. 23.—Monthly production of crude petroleum during 1919 and 1920 by fields. Note the outstanding importance of the Mid-Continent field.

only the decline in demand toward the close of the year to precipitate a falling market.

Trend of Stocks.—Between production and utilization there is a supply of crude petroleum of considerable magnitude held in storage

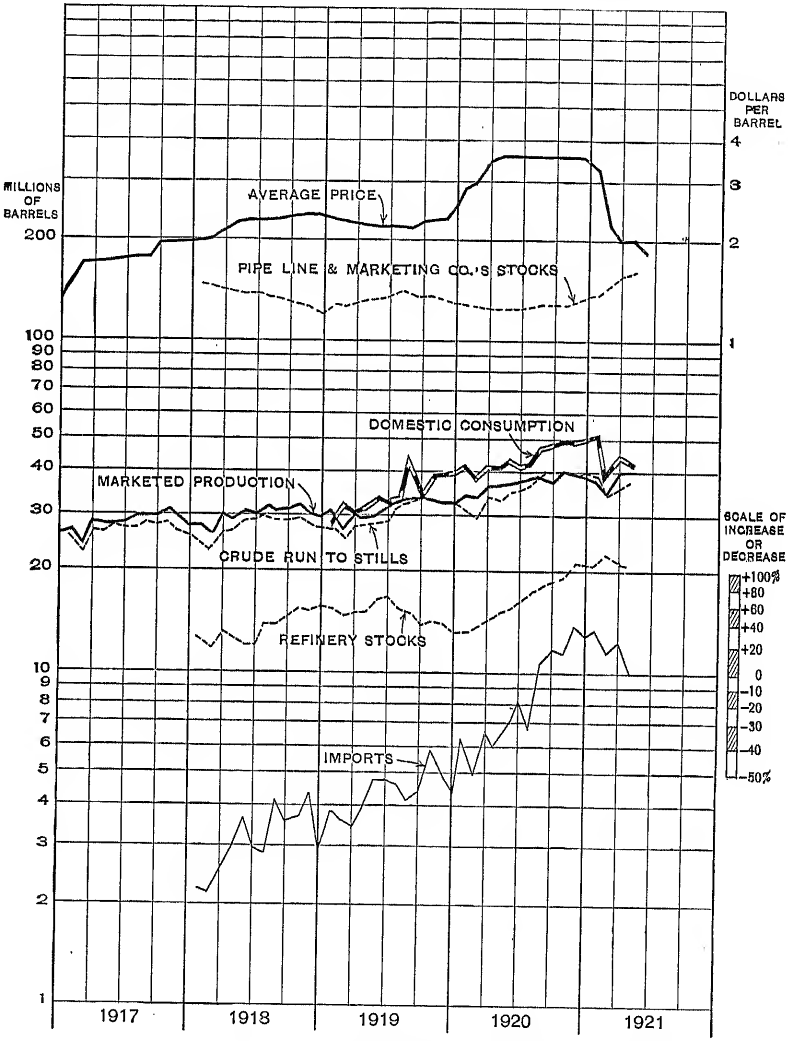


Fig. 24.—Trend of the crude petroleum situation in the United States by months, 1917–1921.

by (*a*) producers, (*b*) pipe-lines and tank-farms, and (*c*) refineries. Beginning August, 1920, the U. S. Geological Survey classified the petroleum in storage according to the division given above, but here-

tofore statistics of stocks have been available for (*a*) pipe-line and marketing companies, and (*b*) refineries. Stocks, as usually referred to in the literature, represent the oil held in storage by the pipe-line and marketing companies, and unless otherwise specified the term is so used in this book.

The size of the country's stocks of petroleum is shown in Table 25 for the period 1913–1920 in comparison with production and consumption. It is apparent that the stocks have for some years averaged around 140 million barrels, although both production and consumption have been rapidly progressing in size. While the stocks from 1913–1916 may have been a trifle ample as a working reserve, the ratio of stocks to consumption has rapidly fallen subsequently. This ratio may be advantageously expressed in terms of the number of months during which the stocks could supply the country's requirements, and the expression shown in Table 26 for 1909–1920 is illuminating, for it indicates that our working reserves of crude petroleum have fallen from an eight-months' supply in 1910 to a three-months' supply in 1920.

TABLE 25.—COMPARISON OF DOMESTIC PRODUCTION AND CONSUMPTION OF CRUDE PETROLEUM BY YEARS, 1913–1920

(Data from U. S. Geological Survey)

(*In millions of barrels*)

Year	Domestic Production	Imports	Exports	Net Imports	Available (Prod. + Net Imports)	Stocks End of Year	Changes in Stocks	Consumption	Crude Run to Stills
1913	248	17.8	4.6	13.2	261	122.8	− 0.1	261	...
1914	266	17.2	2.9	14.3	280	141.6	+18.8	261	191
1915	281	18.1	3.7	14.4	295	163.8	+22.2	273	...
1916	301	20.6	4.0	16.6	318	162.4	− 1.4	319	247
1917	335	30.1	4.0	26.1	361	146.0	−16.4	378	315
1918	356	37.7	4.9	32.2	387	121.7	−24.3	413	326
1919	378	52.8	5.9	46.8	424	127.9	+ 6.2	418	361
1920	443	106	8.0	98.0	541	138.2*	+10.3	531	434

* Includes Mexican stocks held in United States by importers (5.8 million barrels).

Stocks, of course, are a rather sensitive barometer of the month-to-month fluctuations in the relation between supply and demand, any sustained accumulation of stocks being normally followed by a decrease in market price, and vice versa.

TABLE 26.—TREND OF THE STOCKS OF CRUDE PETROLEUM IN THE UNITED STATES IN TERMS OF THE COUNTRY'S REQUIREMENTS

Year	Stocks at End of Year (Millions of Barrels)	Monthly Consumption (Millions of Barrels)	Number of Months Supply Represented by Stocks
1909	117	13.9	8.4 months
1910	131	16.0	8.2 "
1911	137	17.6	7.8 "
1912	123	20.0	6.2 "
1913	123	21.8	5.7 "
1914	142	21.8	6.5 "
1915	164	22.8	7.2 "
1916	162	26.5	6.1 "
1917	146	31.4	4.7 "
1918	122	34.5	3.5 "
1919	128	35.0	3.7 "
1920	134	44.3	3.0 "

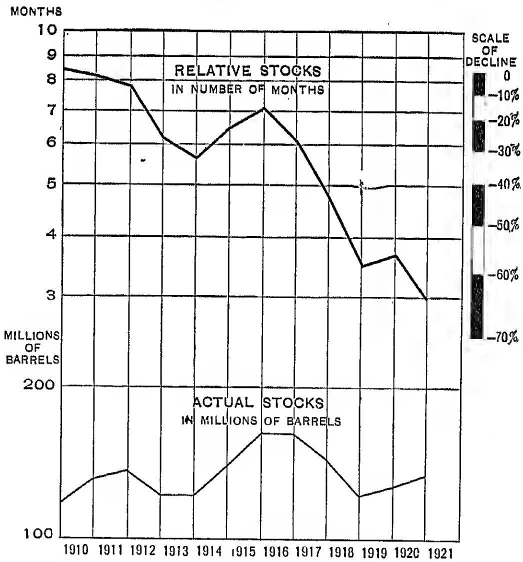


FIG. 25.—Chart showing the change in the actual and relative quantity of crude petroleum in storage in the United States by years, 1909–1920.

Conclusion.—It may be gathered from the data presented in this chapter that the production of crude petroleum in the United States has enjoyed a remarkable and sustained rise to the startling level of 443 million barrels in 1920; that the rapid increase in output

has drawn into production a growing proportion of the resource; that the mounting volume of oil thrown on the market has promoted a wide range of uses which in turn have gathered impetus and stimulated a consumption met with difficulty by the combined production of the United States and Mexico. The situation has shown an accretionary, accelerating growth which cannot be indefinitely sustained and there is much evidence to sound a warning that the turning-point is near when our growing dependence upon petroleum can no longer be met by efforts looking merely to an increase in supply, but changes in technology and economic procedure will be called into action to multiply the service obtained from the quantities available.

CHAPTER V

THE TRANSPORTATION OF CRUDE PETROLEUM

THE liquidity of crude petroleum has led to the development of a remarkable system of transportation without parallel in its cheapness and efficiency. This system comprises a network of pipe-lines spread over much of the country, supplemented by specially designed tank-steamers for coastwise and foreign trade. A relatively small quantity of crude petroleum is handled by the railroads in tank-cars. To a preponderant degree, therefore, the movement of crude oil is independent of the normal transportation agencies upon which commodities in general depend.

Pipe-lines.[1]—The oil pipe-line, first introduced about fifty-six years ago, has so developed that now the American petroleum industry is served by a pipe-line system nearly 50,000 miles in aggregate length, approximately 18 per cent of the combined length of all the railroads. The magnitude of this arterial complex pulsating with oil has been frequently overlooked in considering the rôle played by transportation in the resource development of the United States. A comparison with the railway systems of the country is afforded in Table 27.

TABLE 27.—COMPARISON BETWEEN THE OIL PIPE-LINES AND THE RAILROADS OF THE UNITED STATES

	Number of Miles	Relative, Per Cent	Number of Miles per 100 Square Miles of Territory	Estimated Value (Millions of Dollars)
Oil pipe-lines *....	45,500	18	1.53	500
Railroads †.......	253,626	100	8.53	19000

* Estimated for 1920: Trunk lines, 34,000 miles; gathering lines, 11,500 miles.
† 1917.

[1] For a detailed, though slightly out of date, description of the Mid-Continent pipe-line system, consult Report on Pipe-line Transportation of Petroleum, Federal Trade Commission, 1916. The pipe-lines of Wyoming are described in Report on the Petroleum Industry of Wyoming, Federal Trade Commission, 1921.

As the term is used in the oil industry, a pipe-line is not merely a line of pipe, but consists of the whole plant employed in the process of transportation, including initial, intermediate, and terminal tankage systems, power plants, pumping stations, systems of communication along the line, and all other things necessary to safely and expeditiously move the oil from one point to another.[1] The pipe-line system includes trunk-lines extending from the oil-fields to the refining centers and gathering lines in the producing areas that act as feeders to the main channels. There are approximately 34,000 miles of trunk lines in the United States, the most important being shown in Fig. 26. The combined length of the gathering lines is estimated at 11,500 miles. The relation of gathering lines to trunk lines in a large oil-pool is illustrated in Fig. 27.

The pipes for conveying the oil are made of steel and are laid near the surface of the ground. The main lines average about 8 inches in diameter, with the gathering lines smaller. The oil is forced through the pipes by means of pumps operated by steam or internal combustion engines. The pumping stations in the eastern and mid-western region are usually about 35 miles apart; but in California the average interval is about 12 miles because of the greater viscosity of the oil and the necessity of heating heavy oil to facilitate its movement. The construction cost of most of the lines was about 9000 dollars per mile, based on 8-inch pipe; and the average pumping station cost from 130,000 to 250,000 dollars. In California in 1914 the cost of building an 8-inch line, including stations, was about 20,000 dollars a mile.

Oil is produced from thousands of wells, by hundreds of producers, but for the most part is transported by a few large pipe-line companies. The oil from the wells is first run directly into the producer's tanks, where it has a chance to settle. From there it flows by gravity or is pumped to the pipe-line company's working tanks, either through lines owned by the producer or through gathering lines established by the pipe-line company. The common practice is for the pipe-line company to operate gathering lines which begin at the producer's tanks and to follow up new production with pipe-line extensions.

The carrying capacity of a pipe-line varies with the size of the pipe, the distance between pumping stations, the pressure at which the oil is pumped, and the viscosity of the oil. The cubic capacity of an 8-inch line is 328 barrels per mile. The daily capacity of an 8-inch

[1] For a discussion of the oil pipe-line, consult Forrest M. Towl, Pipe-lines, Existing Facilities and Future Needs, American Petroleum Institute, Nov. 17, 1920.

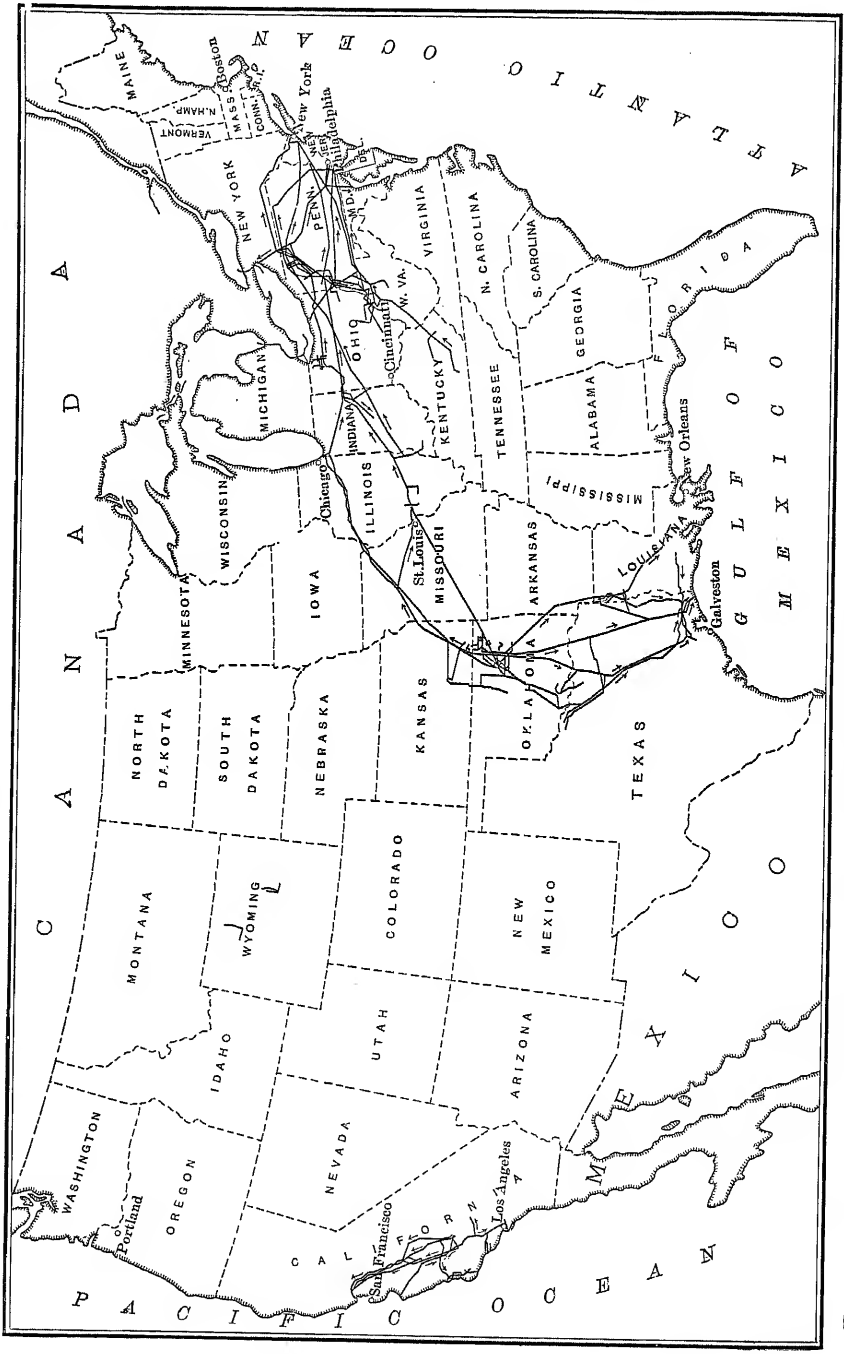


Fig. 26.—Map showing the principal pipe-lines of the United States; after Stratford, based upon a detailed map published by the U. S. Geological Survey.

pipe-line, operating at a pressure of 800 pounds per square inch and transporting oil of 38° Baumé gravity, is 21,000 barrels. The oil in transit in pipes east of California at the end of 1920 was 16,700,000 barrels.

The average daily production of crude petroleum in the United States in 1920 was approximately 1,210,000 barrels. Practically all of this oil was transported by pipe-line. Some of it moved only a few miles, while some was probably carried upward of 1500 miles. About 150,000 barrels per day was taken to the Atlantic seaboard through a connecting system of lines. A large quantity was delivered to Baton Rouge and the Gulf ports through long lines. Probably the entire quantity, approximating 200,000 tons daily, moved on the average more than 500 miles.[1] The movement therefore approximated 100 million ton-miles per day. The daily ton-miles of freight hauled by the railroads of the country are slightly more than 1 billion, indicating that the pipe-line systems reduce the freight load of the United States by something like 10 per cent.

In addition to the tanks that are an integral operating part of the pipe-line system, most of the pipe-line companies provide facilities for storage of crude petroleum in large quantities. Some of the storage-tank farms operated by the pipe-line companies are located in the oil-fields, while others are at convenient points along the line or at its terminus. A tank-farm consists of a group of circular steel tanks, generally of 37,500 to 55,000 barrels capacity, separated by earthen banks as a fire protection. Some of the tank-farms are very extensive, the largest having capacities upward of 10 million barrels. The gross pipe-line and tank-farm stock of crude petroleum east of California at the end of 1920 was 107 million barrels.

Congress has imposed upon the pipe-line companies the obligations of common carriers and has placed them under the supervision of the Interstate Commerce Commission "for the purpose of assuring that the charges and facilities for transportation shall be reasonable and that there shall be no discrimination between shippers." Up to the present, however, comparatively little use has been made of pipe-lines as common carriers, most of the oil produced having been purchased by the pipe-line companies at the producer's tanks, or else handled by integrated interests engaged in the combined activity of production, transportation, and refining. Transportation by pipe-line is, of course, much cheaper than by railroad; and the economy of pipe-line transportation has for the greater part been reflected in lower prices for oil products. The cost of trans-

[1] Towl, loc. cit.

porting crude oil in 1913 from a number of points in the Mid-Continent field to important refining centers is shown in Table 28.

TABLE 28.—COST OF TRANSPORTING CRUDE OIL IN 1913 BY PIPE-LINE
(Data from Federal Trade Commission)

Shipping Point	Destination	Distance (Miles)	Trunk-line Cost per Barrel (Cents)	Gathering-line Cost per Barrel (Cents)	Combined Trunk and Gathering Cost per Barrel (Cents)
Cushing Pool...	Neodesha, Kans.....	117.01	2.64	3.99	6.63
Cushing Pool...	Woodriver, Ill.......	505.54	8.45	3.99	12.44
Cushing Pool...	Griffith, Ind........	686.05	11.03	3.99	15.02
Cushing Pool...	Port Arthur, Tex....	583.09	21.61	5.08	26.69
Glenn Pool....	Baton Rouge, La....	513.60	22.03	3.99	26.02
Electra Pool...	Fort Worth, Tex....	137.74	3.48	5.45	8.93
Electra Pool...	Beaumont, Tex.....	448.82	11.34	5.45	16.79
Electra Pool...	Sabine, Tex.........	479.36	19.16	5.45	24.61

The differences between the published pipe-line tariff rates and railroad rates for shipping crude petroleum is indicated in Table 29.

TABLE 29.—COMPARISON OF PIPE-LINE AND RAILROAD TARIFF RATES FOR SHIPPING CRUDE OIL BETWEEN CHARACTERISTIC POINTS IN 1916
(Data from Federal Trade Commission)

Shipping Point	Destination	Railroad Tariff Rate per Barrel	Trunk Pipe-line Tariff Rate per Barrel	Margin Between Railroad and Pipe-line Rates
Cushing Pool...	Neodesha, Kans.......	$0.311	$0.200	$0.111
Cushing Pool...	Woodriver, Ill.........	.544	.340	.204
Cushing Pool...	Whiting, Ind..........	.622	.420	.202
Cushing Pool...	Cleveland, Ohio.......	.979	.580	.399
Cushing Pool...	Pittsburgh, Pa........	1.054	.590	.464
Cushing Pool...	Buffalo, N. Y.........	1.054	.590	.464
Cushing Pool...	Philadelphia, Pa.......	1.348	.700	.648
Cushing Pool...	Marcus Hook, Pa.....	1.348	.685	.663
Cushing Pool...	Baltimore, Md........	1.320	.700	.620
Cushing Pool...	Bayonne, N. J........	1.403	.700	.703
Cushing Pool...	West Dallas, Tex......	.392	.200	.192
Cushing Pool...	Fort Worth, Tex......	.329	.275	.054
Cushing Pool...	Port Arthur, Tex......	.466	.400	.066
Glenn Pool.....	Baton Rouge, La......	.544	.375	.169

The pipe-line has exerted a far-reaching influence upon the petroleum industry. By rapidly following up new oil-field developments, it has afforded the ever-mounting flow of crude petroleum an outlet

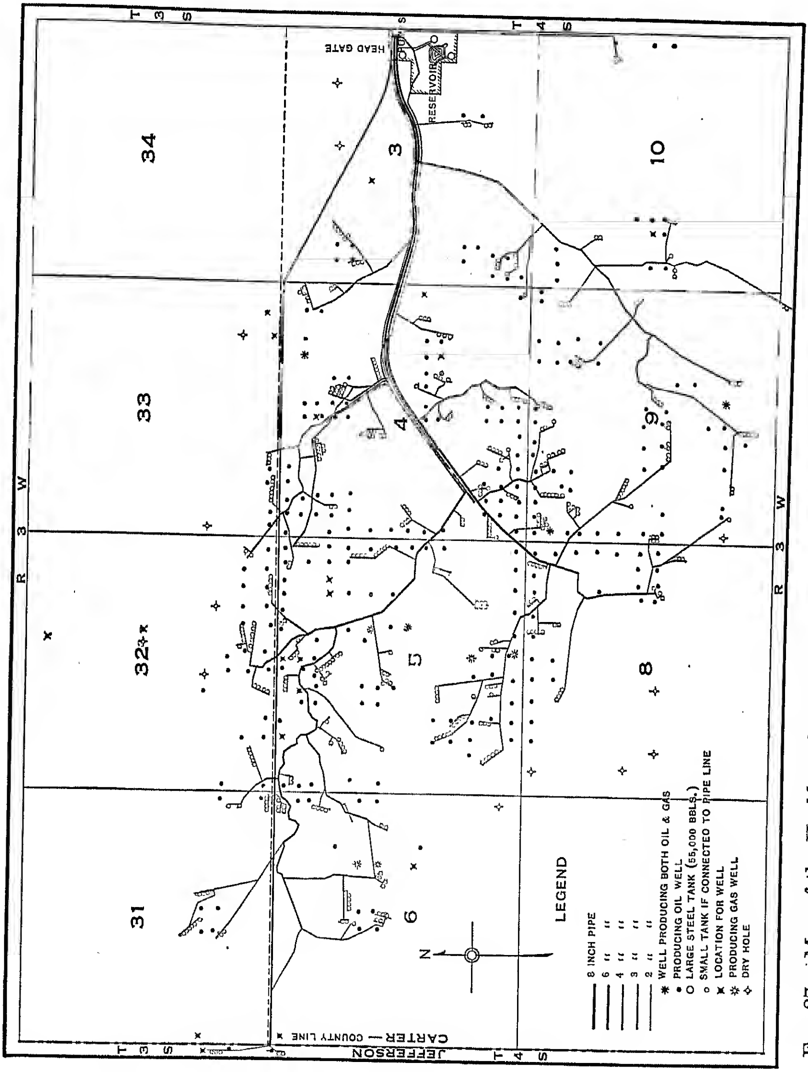


FIG. 27.—Map of the Healdton Oil Pool in Oklahoma, showing the gathering system of a large pipe-line company; after Federal Trade Commission.

to markets. Without the pipe-line, the petroleum resource could not have been brought so rapidly into full production; and, in turn, without the notable growth in oil exploitation that this country has experienced, the pipe-line could not have been stimulated to its present spread. The pipe-line is by nature a large-scale enterprise,

and it is not surprising to find the development of the pipe-line systems of the country largely due to the efforts of large aggregates of capital. According to the Federal Trade Commission,[1] about 69 per cent of the trunk pipe-line mileage of the country is in the hands of the Standard companies and practically all of the remainder belongs to large independent interests. Though interstate pipe-lines are legally common carriers, they are used mainly by the oil companies owning them or affiliated with them. This intimate connection with pipe-line transportation is an important advantage to refineries in obtaining adequate supplies of crude petroleum and getting them at the lowest cost.

While the concentration of pipe-line control has placed the disposition of the crude-oil production of the country for the most part in relatively few hands, the degree of integration attained may be looked upon as the inevitable result of the effort to market adequately the accelerating output of crude petroleum. With production highly individualistic and at all times tending to outstrip developed demands, it devolved upon the manufacturing and distributing activities to facilitate the flow of the raw material to the distributing centers in proximity to demand, if full advantage was to be taken of the opportunities offered. Accordingly the pipe-line became part of the developmental effort, rather than an outgrowth of the competitive, individualistic efforts in the field of production.

Oil Tankers.—For ocean transport, the oil tanker represents the most efficient agency for carrying petroleum, and of recent years, with the development of the oil-fields of the Gulf Coast and Mexico, a growing number of oil tankers have come into use. A comparison of tanker tonnage with the total merchant tonnage for the world is afforded in Table 30.

TABLE 30.—COMPARISON BETWEEN THE OIL-TANKER TONNAGE AND THE TOTAL MERCHANT TONNAGE OF THE WORLD

Year	Tankers (In Thousands of Gross Tons)	Total Steam Tonnage‡ (In Thousands of Gross Tons)	Tankers (In Percentage of Total)
1914	2325*	45,404†	5.1
1920	5216*	53,905†	9.7

* End of year. † June 30. ‡ Lloyd's Register of Shipping

It is thus apparent that the tanker tonnage of the world is not only nearly 10 per cent of the total merchant tonnage, but tanker con-

[1] Report on the Advance in Price of Petroleum Products, Washington, June 1, 1920, p. 21.

struction has been growing at a much greater rate than other types of shipping. Especially has the building of tankers in the United States been speeded up since 1917, as indicated in Table 31.

TABLE 31.—THE GROWTH OF OIL-TANKER TONNAGE IN THE UNITED STATES AND THE REST OF THE WORLD BY YEARS, 1913–1921 *

Year	Number of Tankers			D. W. Tonnage	Per Cent Increase
	American	Foreign	Total		
1913	52	283	335	2,156,987	..
1914	54	290	344	2,325,326	7
1915	92	283	375	2,538,070	9
1916	124	284	408	2,845,414	12
1917	152	301	453	3,331,368	10
1918	189	429	618	4,699,659	41
1919	242	402	644	4,995,122	6
1920	298	376	674	5,215,961	5
1921†	403	512	915	7,554,724	43

* Data from *The Lamp*, April, 1921, p. 5. These figures differ from those reported in Lloyd's Registry of Shipping, but are probably the most accurate compilation available.

† On the assumption that the tonnage building the first of the year will be completed during the year.

The bulk of the international crude-oil movement is between Mexico and the United States. In 1920 roughly 180 million barrels of crude petroleum were moved overseas, of which 106 million barrels, or 59 per cent, represented shipments from Mexico to this country. The net carrying capacity of tank-steamers plying between Mexican and American ports is approximately 6 barrels per deadweight ton. The average tanker running between Mexican harbors and New England or New York is a 10,000-ton tanker or larger, with a capacity of 60,000 barrels or more per trip; the average tank-steamer plying to New Orleans has a tonnage of about 8000 tons and a carrying capacity of about 45,000 barrels; while smaller tankers of 3000 to 5000 tons and oil barges make the run between Tampico and Florida and Texas ports.[1] The average number of barrels transported per tank-steamer trip has increased from about 28,000 in January, 1917, to 48,000 in August, 1920, indicating that larger units are being constantly put into service.

The distance and average round-trip time for a tanker voyage from Tampico to American and other ports are shown in Table 32.

[1] For details regarding the Mexican tanker situation, see V. R. Garfias, Principles Governing Mexican Taxation of Petroleum, Publ. No. 1054, American Institute of Mining and Metallurgical Engineers, Feb., 1921.

Table 32.—Distance and Time Required for Round Trip from Tampico to Selected Ports by Oil Tanker, Average Speed 10 Miles per Hour, with Allowance for Days Lost in Repairs, Dry-docking, etc.
(Data from V. R. Garfias)

Port	Distance, Miles	Time, Round Trip, in Days
Antofagasta, Chile	3668	38
Baltimore, Md.	1951	24
Bayonne, N. J.	2030	25
Beaumont, Tex.	475	12
Boston, Mass.	2276	27
Buenos Aires, Argentina	5518	54
Callao, Peru	2874	32
Canal Zone	1485	20
Freeport, Tex.	474	12
Fall River, Mass.	2131	26
Galveston, Tex.	473	12
Houston, Tex.	473	12

Before the war, tanker tonnage could be contracted for at 70 dollars per ton. During the war the price reached 200 dollars a ton and higher, but in common with prices in general, the price declined to 140 dollars or so by early 1921.

In a 10,000-ton tanker costing 200 dollars a ton, the cost per barrel for transporting oil from Tampico would be as follows: to Texas ports, 42.5 cents; to New Orleans, 53 cents; to Florida ports, 57 cents; and to New York, 88 cents. If the tanker cost only 100 dollars a ton, the transportation costs would become: to Texas ports, 31.8 cents per barrel; to New Orleans, 39.6 cents; to Florida ports, 42.8 cents; and to New York, 65.9 cents. Of the Mexican oil shipped to the United States in 1920, about 54 per cent went to New York and other North Atlantic ports; 26 per cent to Texas ports; and the remaining 20 per cent to New Orleans and Florida ports.

The approximate tonnage of tank-steamers in operation and under construction the first of 1921 by companies exporting Mexican oils is shown in Fig. 28. It is to be noted that if the construction program as indicated in the chart is completed the available transportation will be nearly doubled. Since a Mexican production of 163 million barrels in 1920 was handled by existing tonnage, it would appear that unless Mexican production doubles in 1921, there will be a surplus of tanker transportation facilities. Indeed, tanker construction throughout the world has been overstimulated, at a period of maximum costs, and a surplus of such shipping existed in 1921 as

compared with the oil immediately to be moved. The oil-transporting interests, in consequence, found themselves in somewhat the same plight that befell the United States Shipping Board in its failure to coordinate construction with traffic.

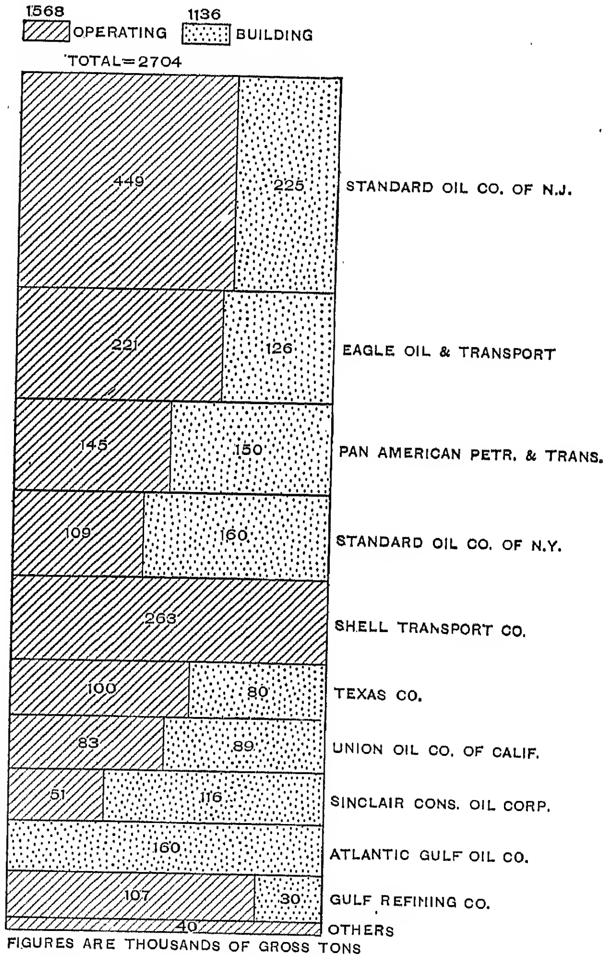


FIG. 28.—Tank steamers in operation and under construction by companies exporting Mexican oils, Feb., 1921; data from V. R. Garfias.

Tank-cars.—Tank-cars are mainly employed for the transportation of petroleum products, although a small percentage of the crude petroleum supply is handled in this manner.[1] Tank-cars of some kind have been in use in the petroleum industry for over fifty years. At the outset they were tub-cars, consisting of a wooden

[1] For an account of the development of tank-cars, see Max Epstein, Tank-cars, American Petroleum Institute, Nov. 17, 1920.

vat or set of vats on a flat car. Soon it became necessary to devise more efficient units, and the forerunner of the modern tank-car was developed, consisting of a steel cylinder strapped to a flat car. There were virtually no standards or rules of construction until 1903, when the Master Car Builders' Association adopted designs and specifications for tank-car construction. The modern tank-car is now "the strongest, most durable, most carefully built freight car in the train."

Originally the tank-car was developed for carrying crude petroleum from the wells to the refinery, the refined products being shipped in barrels. The pipe-line, however, has modernly come to care for the transportation of a growing proportion of the crude petroleum, while the mounting volume of petroleum products to be moved has called for increasing numbers of tank-cars for this purpose. Of recent years tank-cars have been employed mainly for carrying loads from the refinery, and only in minor degree as a feeder to the plant. But as the search for new production proceeds and new or temporary fields are brought in, the tank-car reassumes its original function and handles the crude from fields not yet developed to the degree where pipe-lines may be profitably constructed.

The number of oil tank-cars in operation in the United States is not definitely known, but the approximate number of tank-cars of all kinds in use in this country and Canada is shown in the following tabulation.

TABLE 33.—NUMBER OF TANK-CARS IN THE UNITED STATES AND CANADA ON JANUARY 1, 1914–1921*

1914	49,901
1915	50,899
1916	56,752
1917	67,817
1918	83,918
1919	98,657
1920	110,534
1921	137,493

* Data from *The Lamp*, April, 1921, p. 6.

The majority of the tank-cars in use are owned by oil companies, or by separate tank-car corporations, a small proportion only being controlled by the railroads themselves. The Interstate Commerce Commission has reported that on Jan. 1, 1918, there were 67,000 privately owned and 11,277 railroad-owned tank-cars in service, these figures including cars used for the transportation of other liquid products as well as petroleum oils.[1]

[1] Case No. 4906, In the Matter of Private Cars, Interstate Commerce Commission, April 1, 1918.

CHAPTER VI

TREND OF REFINERY PRACTICE

THE petroleum industry turns out a wide range of commodities under a confusing and perplexing multiplicity of names. The products of major importance, however, are four in number, and the matter may be simplified by viewing the composite output as shown in Table 34.

TABLE 34.—GENERALIZED VIEW OF THE MOST IMPORTANT PETROLEUM PRODUCTS

Major Products	Principal Varieties
Gasoline	Aviation gasoline Motor gasoline Benzine Naphtha
Kerosene	Water-white Standard-white Mineral seal Distillate
Fuel oil	Gas oil Residual fuel oil
Lubricating oils	Neutral oils Cylinder stocks Paraffin oils
Primary by-products	Paraffin wax Asphalt Road oil Petroleum coke
Secondary by-products (fabricated)	Greases Petrolatum Medicinal oils, etc.

The refining of crude petroleum involves the principle of joint-production—the manufacture of a given product necessitating the

output of other products—and this fundamental characteristic of oil refining, in view of the varied types of crude petroleum, the circumstances attending their exploitation, and the rapidly shifting character of the demands for petroleum products, has led to wide local variations in refinery technology in the attempt to fit the supply to the requirements of the country. The basic principles underlying the refining of petroleum have changed very little since the early days of this industry, but the degree to which these principles have been applied has shown a constant evolution from partial to full application as each field of operations has matured. Thus refineries vary from small, rude plants, which merely skim off the lighter components, gasoline and kerosene, selling the residuum as fuel oil, to large, chemically controlled manufactories that turn out the whole range of products obtainable in the present state of the art.

Methods of Refining.—Crude petroleum is manufactured into petroleum products by a process of distillation, by means of which successive components are vaporized and separately condensed, the resultant distillates being then redistilled or chemically purified to yield the finished products entering into commerce. Certain of the compounds, which decompose at temperatures of vaporization, are removed as residual bodies, instead of as distillates.

There are two fundamental types of distillation in general use: (*a*) dry distillation, in which heat is applied directly to the still by coal, gas, or oil fires alone, and (*b*) steam distillation, in which fire is applied to the still but superheated steam is continuously bubbled through the boiling oil.[1]

Dry, or destructive, distillation is the simpler and cheaper method, and is widely employed in new developments and on cheap oil. Its use ordinarily involves some degree of decomposition of the heavier components of the oil, and the viscous or lubricating compounds are impaired in quantity and quality. Dry distillation is employed where the maximum yield of bulk products—gasoline, kerosene, fuel oil—is desired.

Steam distillation is the more involved and expensive method, and is employed by most of the older refineries, where the focus is upon a full extraction of values and especially upon the manufacture of lubricating oils. Its use protects the components of the crude oil from undue decomposition during the course of distillation, as the steam has the effect of lowering the boiling points of the hydrocarbons.

[1] A good technical description of oil refining is given by C. W. Stratford, Petroleum Refining, Journal of the Society of Automotive Engineers, July, 1918, pp. 69–87.

With two basic methods of refining, three groups of crude petroleums (paraffin-base, mixed-base, and asphalt-base), and a varied economic setting in respect to the products that may profitably be disposed of, a great many different types of refineries have developed. It is impossible to make a rigorously logical classification of refinery types, but in a general way oil refineries group themselves as follows:

TABLE 35.—IMPORTANT TYPES OF REFINERIES

Name	Method of Distillation	Kind of Crude	Economic Focus
1. Skimming plant...	Dry	Mixed and paraffin-base	Light products (gasoline and kerosene)
2. Intermediate plant	Dry	Mixed-base	Light products; some lubricants
3. Complete plant....	Steam	Paraffin-base	Lubricants; light products
4. Complete plant....	Steam	Mixed-base	Lubricants; light products
5. Complete plant....	Steam	Asphalt-base	Lubricants; light products
6. Topping plant.....	Dry	Asphalt-base	Fuel oil

The characteristic yields of the six major refinery types are shown graphically in Fig. 29. The methods of manufacture followed in each case are different; and brief descriptions, emphasizing the economic characteristics, are given below.

Skimming Plants.[1]—Skimming plants, as the name implies, remove only the lighter fractions from the crude petroleum, and are not concerned with the manufacture of products from the heavy residues, which are lumped together and sold as fuel oil. (See Fig. 29*a*.) The skimming plant is the simplest and cheapest type of refinery and makes merely a rough separation of the raw material into a few products in ready demand. Around 40 per cent of the refinery capacity of the United States is of the skimming type, the bulk of the installations being in the Mid-Continent region in proximity to producing fields yielding oils rich in gasoline.

Skimming plants produce a notable proportion of the country's gasoline supply, but are wasteful of the lubricating values contained in the oil. They are very profitable where accessible to cheap oil, but quickly become uneconomic when adjacent fields decline in

[1] Refinery types are discussed by H. H. Hill, Refinery Problems, U. S. Bureau of Mines, 1920.

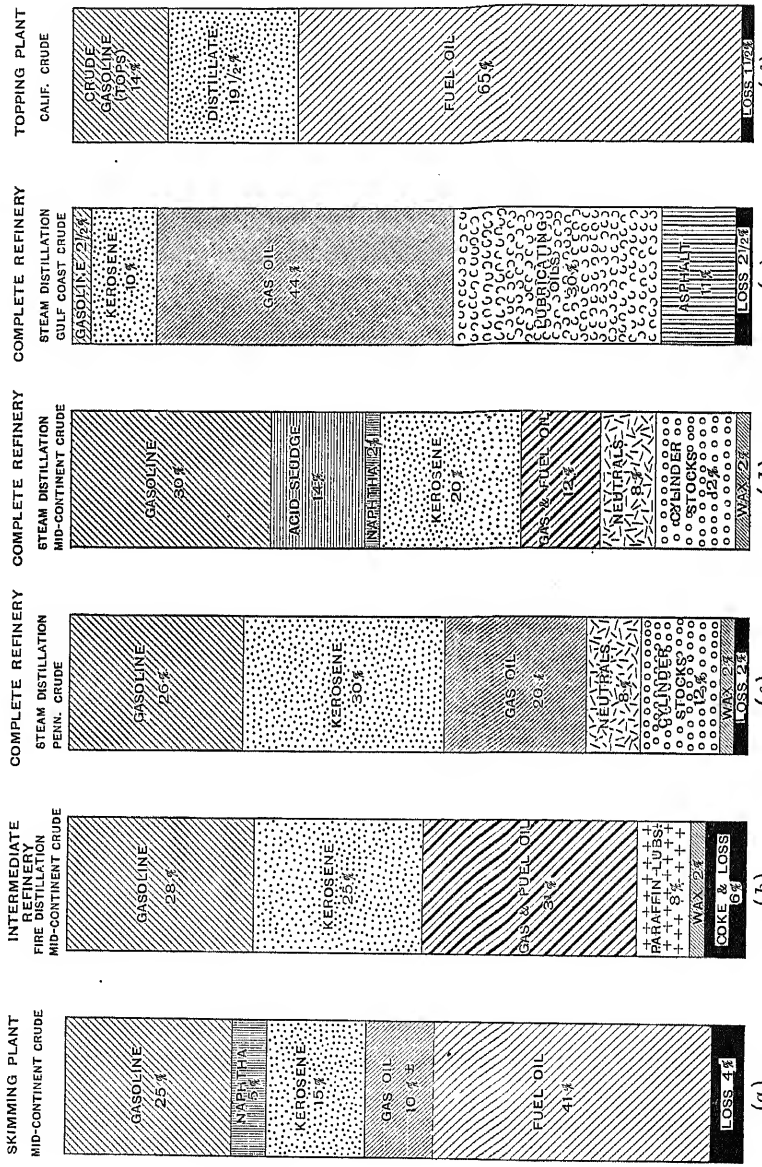


FIG. 29.—Chart showing the average yields from the principal types of refinery practice in the United States; data from Geo. B. Gifford.

output or when the price ratio becomes unfavorable to this type of plant. The skimming plant is an accompaniment of flush production, springing up quickly and as quickly becoming dormant as circumstances shift. In many instances, skimming plants are changed into intermediate plants (Type 2, Table 35, and Fig. 29*b*) by the addition of re-run stills and equipment for the removal of wax and the treatment of the heavier distillates, thus evolving into refineries capable of manufacturing lubricating oils.

Intermediate Refineries.—Refineries employing dry distillation, operating mainly on mixed-base crudes, and focusing upon light products, with incidental attention to the manufacture of lubricating oils, though usually called complete refineries, may be appropriately termed intermediate refineries. The yield of a typical plant of this

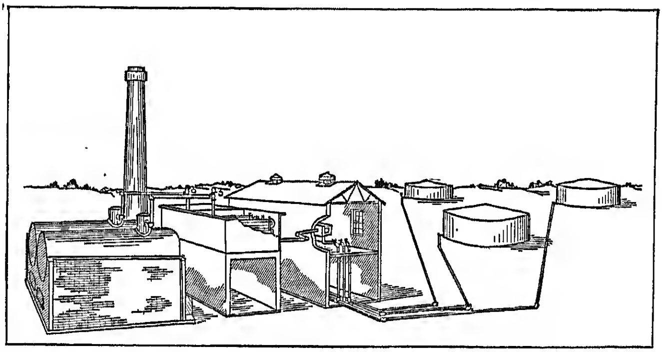


FIG. 30.—Sketch of a typical small skimming plant in the Mid-Continent Field. after R. W. Cunningham.

type operating on Mid-Continent crude is shown in Fig. 29*b*. As the term intermediate implies, plants of this type are one stage removed from skimming plants, but they do not take full advantage of the viscous components of the crude; they extract these but partially and in the form of so-called paraffin lubricating oils, with yields smaller in volume and inferior in worth to the lubricating oils obtainable from the same crude in complete refineries employing steam distillation.

Complete Refineries.—Complete refineries are those making relatively a full extraction of values by the method of steam distillation. The details of a complete refinery differ according to the type of crude employed; and in general these differences are such that complete refineries may be subdivided into three varieties: (1) those handling Pennsylvania, or paraffin-base crudes, (2) those employing Mid-Continent, or mixed-base crudes, and (3) those running Gulf Coast, or asphalt-base crudes.

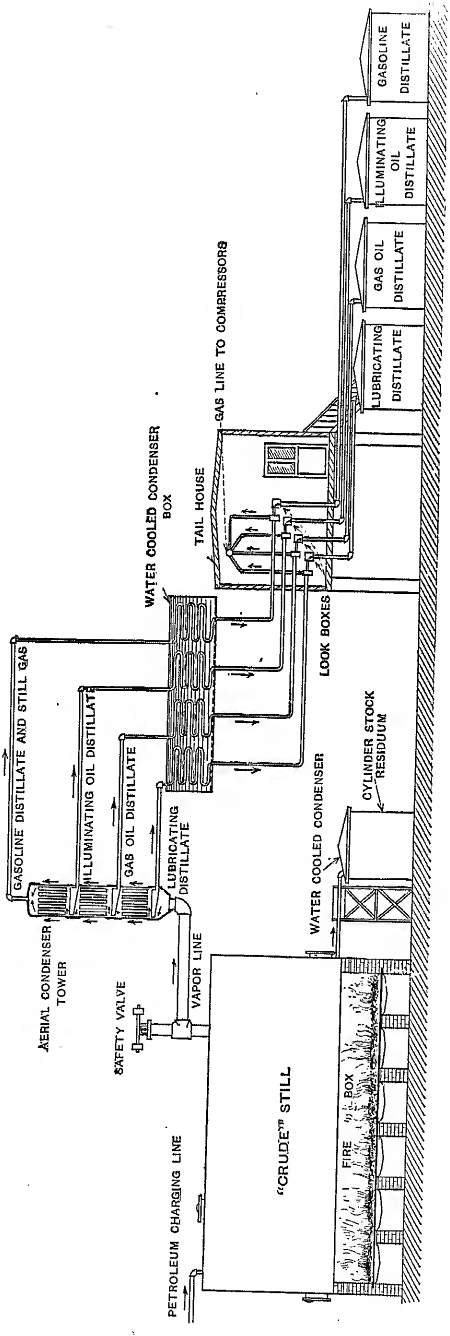


FIG. 31.—First stage in the refining of crude petroleum by steam. (*Courtesy of Tide Water Oil Company*)

The Pennsylvania type of complete refinery is the most mature and the best known. (See Fig. 29*c*.) Its refinery practice is dictated by the focus upon obtaining the maximum yield of lubricating oils, especially the viscous variety known as cylinder stock. Because the lighter products of paraffin-base crudes are readily distilled off, while the components of the cylinder stock decompose upon vaporization, the latter is recovered as a heavy residual oil which yields finished cylinder stock upon subsequent treatment. The distillation can be conducted in this manner because the crude petroleum contains no asphaltic material which would be left behind as a contamination in the residual cylinder stock. The characteristic practice in steam-refining Pennsylvania crude oil is shown diagrammatically in Figs. 31 and 32.

With mixed-base petroleum, such as much of that produced

in the Mid-Continent field, the complete refinery is forced to vary its practice in order to remove the asphaltic content at a relatively early stage in the distillation process and thus prevent its accumulation

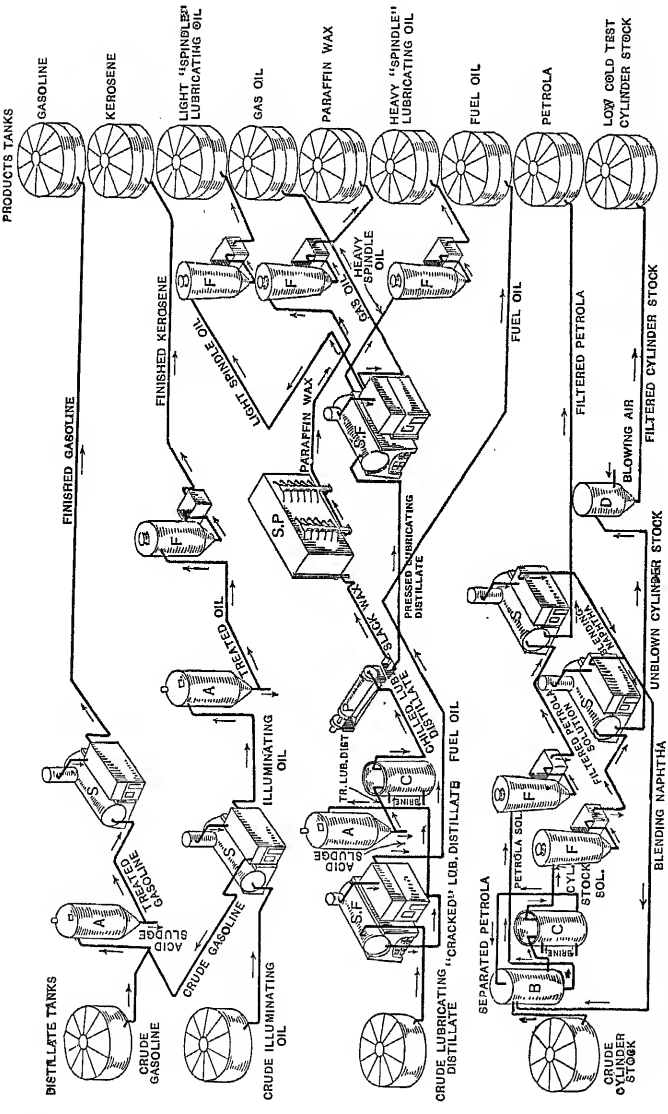


FIG. 32.—Final stages in the refining of crude petroleum by steam. Usual practice with Pennsylvania crude. (*Courtesy of Tide Water Oil Company*)

KEY TO EQUIPMENT

A. Agitators
B. Blending Tanks
C. Chillers
D. Dehydration Tank
F. Filters
P. Wax Press
S. Steam Stills
S.F. Steam and Fire Stills
S.P. Wax Sweater Pans

along with the residual cylinder stock at the end. (See Fig. 29*d*.) This is accomplished, after the gasoline has been distilled off, by treating the oil with sulphuric acid, which precipitates the heavy asphaltic bodies in the form of an acid sludge; the remaining oil is

then subjected to further distillation, cylinder stock being left as a final residual product.

With asphaltic crudes, such as those of the Gulf Coast, the complete refinery may still further vary its practice, and in the direction of simplification, since in crudes of this type the entire lubricating content may be distilled off (because their boiling points are lower than the lubricating components of corresponding viscosity in paraffin-base crudes). Thus the asphaltic content offers no particular difficulty, since it may be left to constitute the residuum, the lubricating oils having passed off as distillates. Refineries of this type have enjoyed a notable development in the past few years in the Gulf Coast region, and have opened to full utilization a type of crude employed mainly heretofore in the manufacture of fuel oil.

Topping Plants.—A variant of the skimming plant, used for heavy crudes such as those of California and Mexico which contain small percentages of light components, is the so-called topping plant. This type of refinery is concerned primarily with the production of fuel oil, removing from the crude oil the volatile components which, if left in the fuel oil, would render it unsafe for general use. These light liquids are called tops and distillates and correspond roughly to the gasoline, naphtha, and kerosene of skimming plants. The difference between a topping and skimming plant is primarily one of economic focus, arising from the type of crude oil available; both are immature, effecting merely a rough separation of values.

Topping plants are numerous in California, and of late a large capacity has been installed along the Atlantic Seaboard to handle the quantities of Mexican oil coming into this country. The yield of a typical topping plant is shown in Fig. 29*f*.

Refineries with Cracking Plants.—In many refineries are supplementary batteries of pressure stills employed in converting gas oil partly into gasoline under the application of high temperature and pressure. Most of the installations of this kind are attached to the larger complete refineries. The raw material and typical yield of the process is shown in Fig. 33. Cracking installations have developed and expanded in response to a demand for gasoline that is outdistancing the ability of normal refining, thus calling into play an enforced yield in addition to that ordinarily obtainable. In 1920 perhaps as much as a tenth of the country's entire supply of gasoline was made in pressure stills from gas oil.

The growth of cracking has created a number of problems of the first importance which are treated in detail in subsequent chapters.

Trend of Refinery Types.—It is evident from this brief analysis of the refinery situation that there are four stages in the evolution of refinery practice, through which the refineries of the country are in general passing. At the outset of new developments, with cheap and abundant crude petroleum, skimming and topping plants develop according to the type of crude; then, with advancing conditions, these incomplete plants either fail or else change into intermediate refineries that effect a fuller extraction of values; later, with increasing stress, the growth is in the direction of complete refineries, in which fuller advantage is taken of the potentialities present in the crude oil; and finally pressure stills are installed to carry the extraction of values still further by converting a low-value product into one of greater worth. While this evolutionary trend is not entirely sharply defined, and local complications are present, it is practically certain that ultimately the complete plant with cracking installations will quantitatively dominate the situation, just as this type of plant now leads in economic and financial strength.

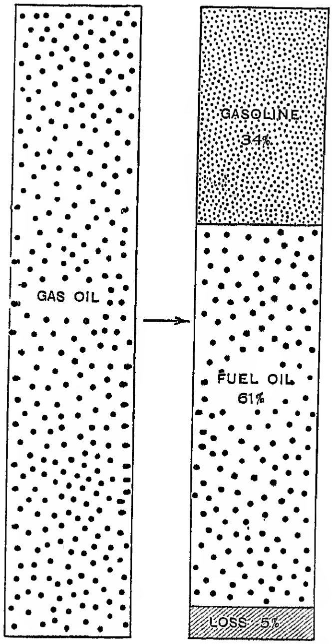


FIG. 33.—Chart showing typical practice in manufacturing cracked gasoline.

Trend of Refinery Output.—The trend in output of the principal petroleum products in the United States over the period for which figures are available is shown in Table 36 and Fig. 34. Fig. 34 is a ratio chart in which the slopes of the curves are proportional to the percentage changes; it may be observed that the production of gasoline and fuel oil has been increasing at a notable rate, and one in excess of the increase in output of crude petroleum. The production of lubricating oils and kerosene, on the other hand, has been increasing less strikingly and at a much slower rate than crude petroleum. With due allowance for imported crudes, there is evidently a shift taking place in the proportionating of the output in favor of gasoline and fuel oil. This arises of course from the mounting requirements of automotive transportation, which have sent the demand for gaso-

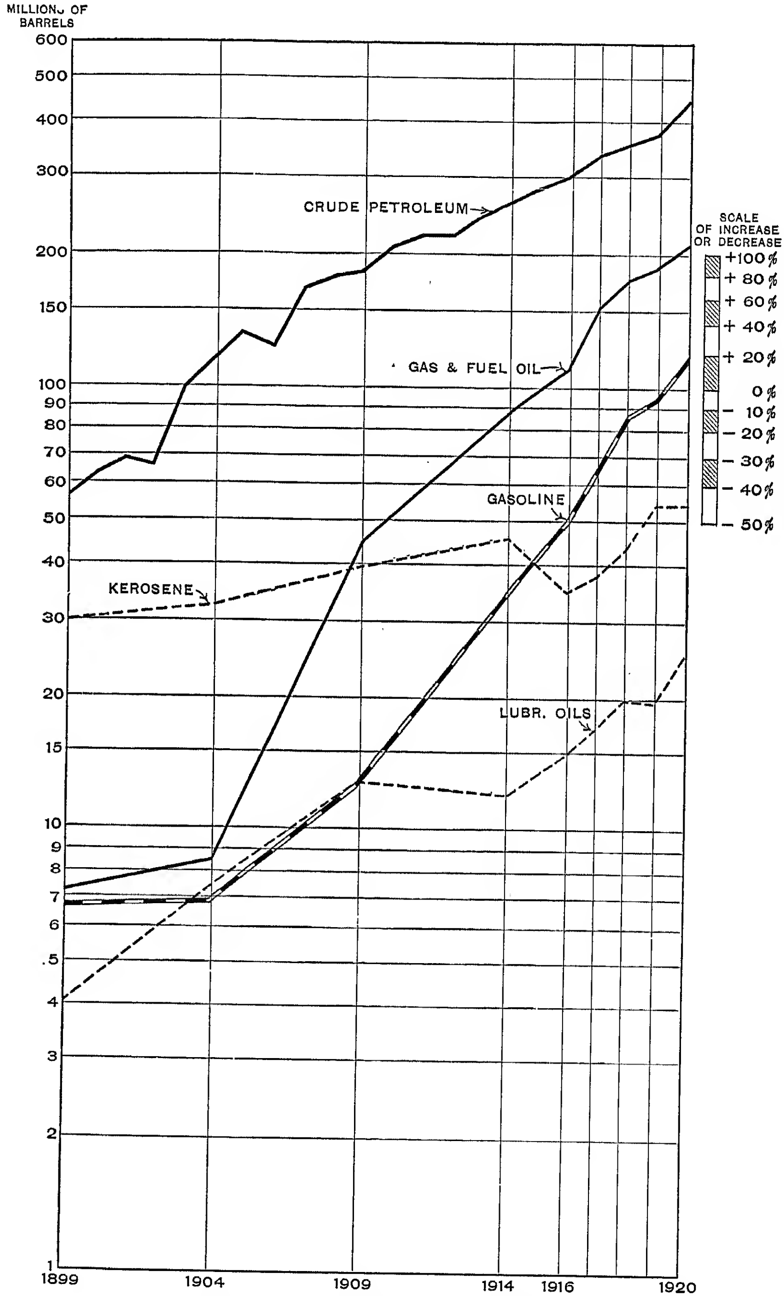


FIG. 34.—Trend in output of crude petroleum and its principal products in the United States, 1899–1920.

line insistently forward, supported by the vigorous development of the oil-fields of this country and Mexico. The production of kerosene and lubricating oils has followed along to the capacity of their respective demands, much of the potential lubricants having of necessity to be marketed in the form of fuel oil.

Production of Petroleum Products in Recent Years.—The output of the principal petroleum products by years from 1917–1920 is shown both statistically and graphically in Fig. 35. It is to be observed that enormous volumes of these materials are manufactured and a notable advance in output has recently taken place. The change in the relative importance of the products is shown in the percentage comparison in the right-hand half of the chart. The increase in the relative output of gasoline is especially noticeable.

TABLE 36.—PRODUCTION OF THE PRINCIPAL PETROLEUM PRODUCTS IN THE UNITED STATES, 1899–1920

Year	Gasoline			Kerosene			Gas and Fuel Oil			Lubricating Oils		
	Prod. Mill. Gals.	Index Nos.	Yearly Change	Prod. Mill. Gals.	Index Nos.	Yearly Change	Prod. Mill. Gals.	Index Nos.	Yearly Change	Prod. Mill. Gals.	Index Nos.	Yearly Change
1899*	281	18	.....	1259	65	.....	305	8	.....	170	33	.....
1904*	291	19	.....	1357	70	.....	360	10	.....	315	61	.....
1909*	540	36	.....	1675	85	.....	1702	46	.....	537	103	.....
1914*	1500	100	.....	1935	100	.....	3734	100	.....	517	100	.....
1916†	2059	137	.....	1455	75	.....	4664	125	.....	624	121	.....
1917†	2851	190	+38%	1727	89	+19%	6513	174	+40%	754	146	+21%
1918†	3570	238	+25%	1825	94	+ 6%	7321	196	+13%	841	162	+11%
1919†	3958	264	+10%	2342	121	+28%	7627	204	+ 4%	847	164	+ 1%
1920†	4883	325	+23%	2320	120	− 1%	8861	238	+16%	1048	203	+24%

* Census of Manufactures. † U. S. Bureau of Mines.

Source of Petroleum Products.—The proportions of the principal petroleum products manufactured in various parts of the country are shown in Table 37, the outputs of each product being grouped according to refinery districts.

The data presented in Table 37 are graphically interpreted in Fig. 36, in which the relative contribution of each product made by various parts of the country may be conveniently viewed.

Relation of Refining Costs to Crude Costs.—In the refining of petroleum, the cost of the crude oil is the largest factor, in many instances running up to 70–80 per cent of the total costs. Data for 1917 for a number of refineries are shown in Table 38 as indicative of the situation:

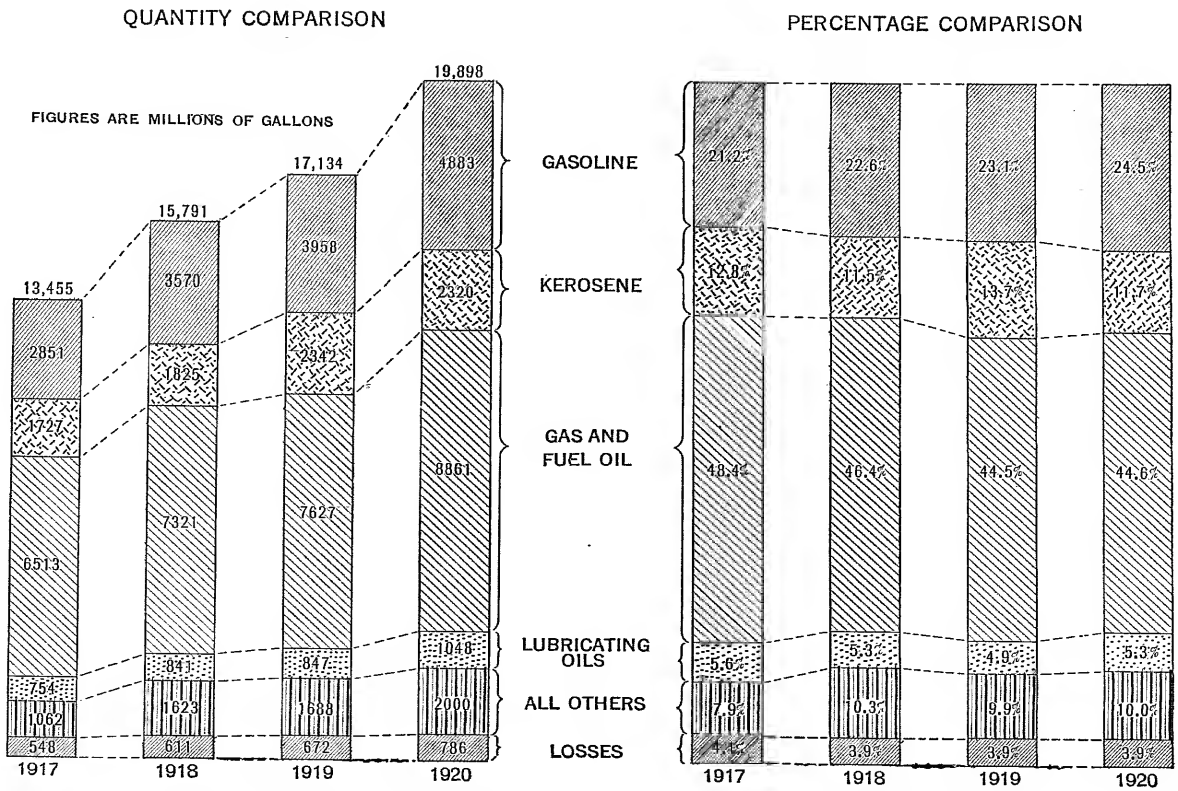


FIG. 35.—Production of petroleum products in the United States by years, 1917–1920.

TABLE 37.—OUTPUT OF THE PRINCIPAL PETROLEUM PRODUCTS IN THE UNITED STATES IN 1920 BY REFINERY DISTRICTS

Refinery District	Gasoline, Per Cent	Kerosene, Per Cent	Gas and Fuel Oil, Per Cent	Lubricating Oils, Per Cent	Others, Per Cent
East Coast	19.9	21.4	21.9	31.5	14.0
Penn., etc.	5.9	7.5	2.3	18.2	3.4
Ill.-Ind., etc.	14.4	9.4	6.4	12.1	13.7
Kan.-Okla., etc.	20.0	17.0	15.1	8.7	6.4
Tex.-La.	23.4	30.8	27.0	19.3	28.0
Wyo.-Colo., etc.	6.2	5.0	2.4	1.4	15.3
Calif.	10.2	8.9	24.9	8.8	19.2
Total	100.0	100.0	100.0	100.0	100.0

TABLE 38.—RELATION OF OPERATING COSTS TO CRUDE COSTS IN A NUMBER OF AMERICAN REFINERIES IN 1917

Data from Oil Division, U. S. Fuel Administration.

Refinery	Location	Cost of Crude, Per Cent	Operating Costs, Per Cent	Total, Per Cent
No. 1	East	78	22	100
No. 2	East	79	21	100
No. 3	East	70	30	100
No. 4	Middle West	80	20	100
No. 5	Middle West	84	16	100
No. 6	Oklahoma	87	13	100
No. 7	Texas	80	20	100

TABLE 39.—RELATION OF CRUDE COST TO REFINING COSTS IN CALIFORNIA IN 1914 AND 1919, BASED ON DATA FOR 15 REFINERIES

(In Per Cent)

Item	1914	1919
General and administrative expense, and depreciation	7.1	8.3
Refinery operating expense	13.5	17.7
Delivered cost of crude	79.4	74.0
Total	100.0	100.0

The relation of the cost of raw material to refining cost is shown for California in Table 39 from figures compiled by the Federal Trade Commission [1] for 15 refineries representing a total investment of 47 million dollars out of a total for the state of 50 million dollars.

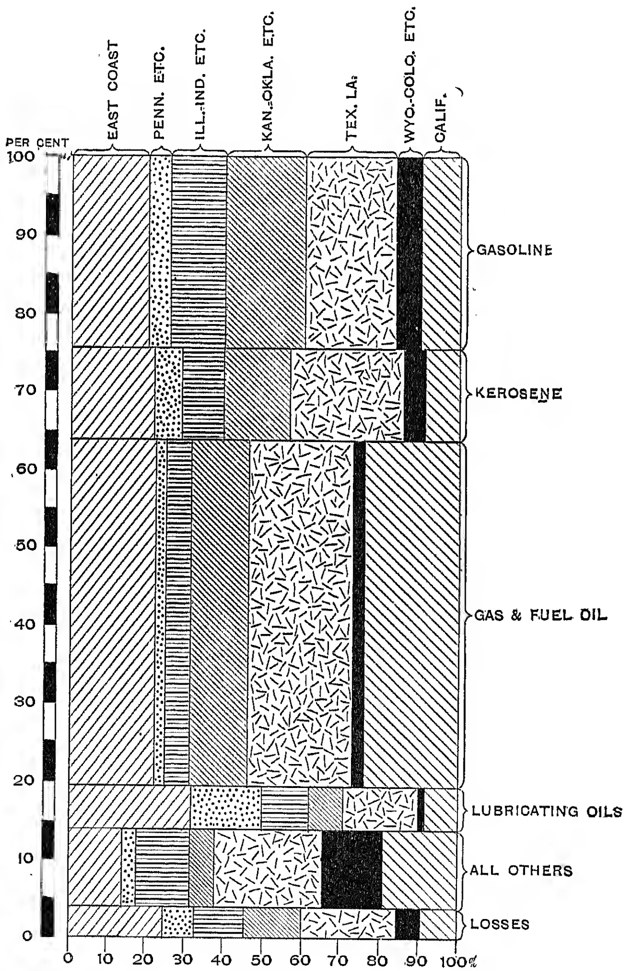


FIG. 36.—The output of petroleum products in the United States in 1920 by refinery districts.

Relation of Labor Costs to Refinery Output.—The ratio of man-power to the volume of materials handled in oil refining is small, as compared with the run of manufacturing operations. An indication of this relationship is shown in Table 40.

[1] Summary of Report on the Pacific Coast Petroleum Industry, April 7, 1921, p. 13.

TABLE 40.—RELATION OF MAN-POWER TO MATERIALS HANDLED IN AMERICAN PETROLEUM REFINERIES DURING FIRST SEVEN MONTHS OF 1918

(Data from U. S. Fuel Administration)

Number of Refineries	Location	Average Number of Barrels Run Daily per Man	Average Wages per Barrel Run, Cents
6	East Coast	9.37	46
33	Eastern	10.04	37
7	Illinois and St. Louis	9.80	44
6	Northern Texas	74.00	5
5	Gulf	31.10	13
38	Oklahoma	27.00	15
2	Rocky Mountain	42.40	14
12	Pacific Coast	31.80	14
109	Country	17.57	24

Rank of Petroleum Products.—The relative importance to the oil refiner of the products manufactured from crude petroleum is indicated in Table 41, which shows the average returns per barrel of crude petroleum refined in 1918.

TABLE 41.—ESTIMATED AVERAGE RETURNS PER BARREL OF CRUDE PETROLEUM REFINED IN 1918

(Data from Bureau of Engineering, Oil Division, U. S. Fuel Administration)

Rank	Product	Dollars	Per Cent of Total
1.	Gasoline	1.922	44.5
2.	Gas and fuel oil	1.213	28.2
3.	Lubricating oils	.419	9.7
4.	Kerosene	.378	8.8
5.	Wax	.121	2.8
6.	Asphalt	.042	0.95
7.	Coke	.0069	0.15
	All others	.210	4.9
	Total	4.31	100.0

It is apparent from this table that gasoline represented nearly half of the income to the average refinery in 1918—to such an extent has the oil industry become involved in the field of automotive transportation.

CHAPTER VII

ANALYSIS OF REFINERY CAPACITY

There are approximately 500 petroleum refineries in the United States ranging in size from plants capable of running 500 barrels of petroleum daily or even less to large manufactories equipped for handling upwards of 40,000 barrels each day. These plants in the aggregate represent a refining capacity in excess of the crude petroleum available as well as in excess of requirements for refined products; a large proportion of the plants are grouped about the oil-fields at a distance from the markets; and many turn out a very limited range of products with a sacrifice of values. The oil-refining industry as a whole has grown somewhat out of adjustment to supply, demand, markets and other factors to which it is geared, and a considerable readjustment in the structure of this portion of the petroleum industry is taking place and lies ahead. In view of this circumstance, it is important to analyze the location, size, type and degree of utilization of the country's refinery capacity, with a view to determining the stability attained and the extent of the changes in prospect.

Location of Refinery Capacity.—In spite of the development of an extensive pipe-line system for transporting crude petroleum to the consuming centers for manufacture there into petroleum products, a large share of the refinery capacity of the country is in those states producing petroleum in great quantities, such as Texas, California, Oklahoma, Pennsylvania, Louisiana, Kansas, and Wyoming. The degree to which refining is centered in the oil-producing states is graphically shown in Fig. 37, where New Jersey stands out as the marked exception to this rule.

The number, size and location of refineries are given in greater detail in Table 42, where figures for a number of years permit a view to be had of the location of new developments. It will be observed that points along the East Coast, and the states recently coming into prominence as oil producers (Texas, Louisiana, and Wyoming), show the most marked growth in refinery installations.

Size of Refineries.—The average capacity of the refineries of the country is approximately 4500 barrels a day. The largest refineries,

as readily apparent from Table 42, are in New Jersey, with an average capacity of 27,000 barrels daily; the largest of the New Jersey plants is at Bayonne, with a daily capacity of 40,000 barrels. To indicate in further detail the range of refinery capacities in the various parts of the country, recent refinery statistics have been first grouped into

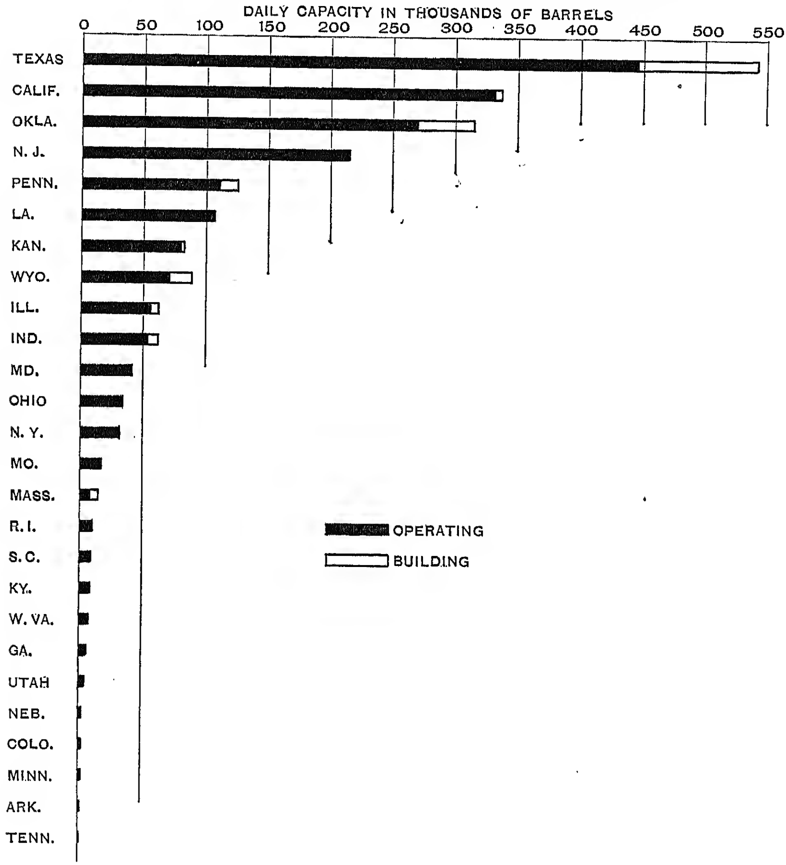


FIG. 37.—Refinery capacity of the United States in Oct., 1920, by states; data from Oil Weekly.

the six refinery districts established by the U. S. Bureau of Mines in reporting refinery output and then classified into five groups according to size. The results are shown in Table 43 and graphically interpreted in Fig. 38. The dominance of refineries above 10,000 barrels daily input is at once apparent, while the relatively extensive installations of refineries running 5000 barrels and under in the Kansas-Oklahoma and Texas-Louisiana regions are equally striking.

The overwhelming preponderance of refinery capacity in the south-central states and near the Atlantic and Pacific seaboards is no less notable. Fig. 38 will bear careful comparison with Fig. 2 showing

TABLE 42.—GROWTH OF THE REFINERY CAPACITY OF THE UNITED STATES BY STATES, 1918–1921

(Data from U. S. Bureau of Mines)

States	Number of Refineries, Jan. 1					Daily Capacity of Refineries, Jan. 1 (In Thousands of Barrels)					Average Size of Refineries Jan. 1, 1921 (In Thousands of Barrels per Day)
	1918	1919	1920	1921	Building Jan. 1, 1921	1918	1919	1920	1921	Building Jan. 1, 1921	
Texas	22	26	64	82	19	195	212	317	366	41.7	4.5
California	38	37	41	41	.....	283	281	310	313	......	7.6
Oklahoma	64	79	87	91	8	204	233	249	277	7.50	3.5
New Jersey	5	4	7	8	1	94	100	111	217	6.00	27.2
Louisiana	10	12	13	19	6	66.9	67.9	72.6	120	5.00	6.30
Penn	50	48	56	55	.....	85.4	90.9	102	118	......	2.1
Kansas	27	31	33	34	1	59.5	71.4	80.2	84.7	0.20	2.5
Wyoming	4	5	10	13	.....	31.8	52.3	61.0	66.7	......	5.1
Illinois	10	11	14	12	.....	35.9	46.0	58.0	54.6	......	4.6
Indiana	1	2	3	4	2	30.0	36.5	47.2	53.2	1.20	13.6
Maryland	4	4	4	4	.....	15.5	15.5	15.5	42.0	......	10.5
New York	7	7	7	7	.....	33.5	34.5	34.5	35.0	......	5.0
Mass	.....	.....	.....	3	.....	......	......	......	35.0	......	11.7
Ohio	10	10	10	12	1	24.4	24.4	24.4	34.5	......	2.9
Missouri	5	5	4	5	.....	16.2	16.4	15.8	17.0	......	3.4
Kentucky	.....	2	6	7	3	......	2.60	11.7	15.2	3.00	2.2
R. I.	.....	.....	.....	2	.....	......	......	......	15.0	......	7.5
W. Va.	5	5	5	5	.....	7.60	7.70	7.90	7.70	.....	1.5
Virginia	.....	.....	.....	1	.....	......	......	......	5.00	......	5
Georgia	.....	.....	1	1	.....	......	......	4.00	4.00	......	4
Utah	1	1	1	1	1	0.80	0.80	0.80	4.00	0.05	4
Colorado	2	2	3	3	.....	1.25	1.50	1.70	1.75	......	0.6
Nebraska	.....	.....	1	2	.....	......	......	0.50	1.50	......	0.8
Minnesota	.....	1	1	1	.....	......	0.30	1.50	1.00	......	1.0
Arkansas	1	1	1	1	.....	0.30	0.30	0.60	0.50	......	0.5
Tennessee	1	.....	1	1	.....	0.50	.....	0.50	0.50	......	0.5
S. Carolina	.....	.....	.....	.....	1	......	......	......	......	10.00	....
New Mex.	.....	.....	.....	.....	1	......	......	......	......	2.00	....
Total	267	289	373	415	44	1186	1295	1531	1888	76.6	4.5

the oil-fields of the country. If the industrial and agricultural density of the country is held in mind, the analysis of refinery figures just given will point to the regions where further refinery develop-

ments are likely to take place. It is quite apparent that refinery installation is unduly concentrated in the south-central states and a high refinery mortality is in consequence to be looked for in that region.

Types of Refineries.—An economic classification of refineries into fundamental types has been given on page 77. Unfortunately

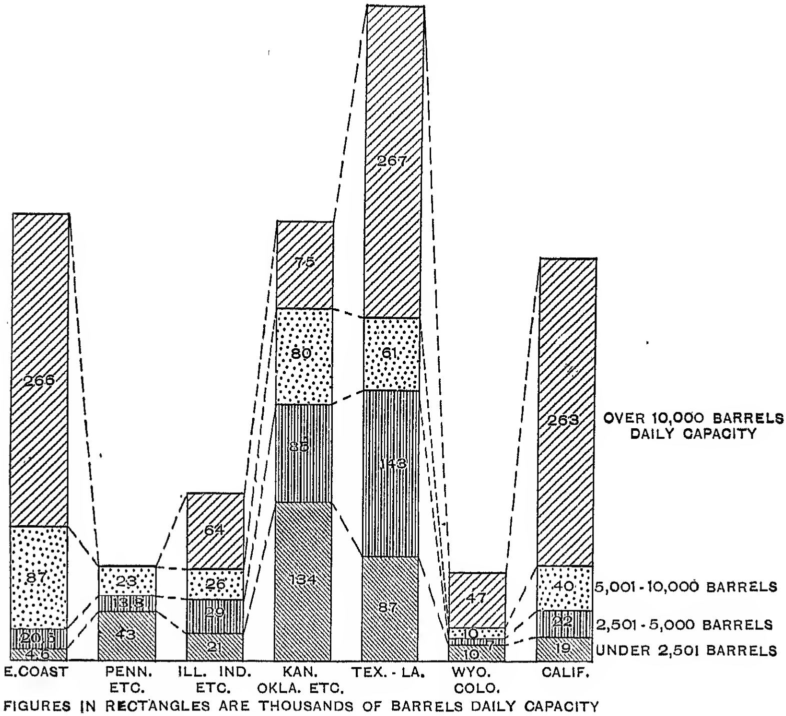


FIG. 38.—Refinery capacity in various parts of the country, Oct., 1920, by sizes of refineries; data from Oil Weekly.

statistical data are wanting for measuring the aggregate capacity of each type. The Bureau of Mines, however, has published a list of refineries [1] in which each refinery is classified according to the range of products turned out. This list yields information of value with reference to the relative importance of the refinery types, although the figures must be used with some discretion, since a single plant may include two or more components of different character. For example, many of the refineries along the East Coast classified by the

[1] Petroleum Refineries in the United States, January 1, 1921, U. S. Bureau of Mines.

Bureau of Mines as complete plants are really dual plants, comprising a complete refinery and in addition a topping plant.

TABLE 43.—REFINERY CAPACITY OF THE UNITED STATES IN OCTOBER, 1920, BY REFINERY DISTRICTS AND SIZES OF REFINERIES *

(In thousands of barrels per day)

Refinery District	Under 1001 Barrels	1001–2500 Barrels	2501–5000 Barrels	5001–10,000 Barrels	Over 10,000 Barrels	Total
East Coast........	2.1	2.5	20.5	86.5	266 15†	378 15†
Penn, etc..........	29.3 .5†	13.5	13.3	22.9	....	79 .5†
Ill., Ind., etc.......	8.9 1.5†	12.3 1.3†	29 5†	26.5 6†	64	141 14†
Kan.-Okla., etc.....	..36.9 9.2†	97.2 15.2†	85.4 12.5†	79.5 6.5†	74.5	373 43†
Texas–Louisiana...	25.5 12.2†	62 16†	143 15†	60.5 36†	267 108†	557 187†
Wyo.-Colo., etc....	4.2 2.1†	5.5	7.5	10 17†	47	74 19†
California.........	10.7 .3†	8.6	21.7 3†	40	263	344 3†
Total.......	118 25.6†	202 32.5†	325 35.5†	287 65.5†	1015 123†	1946 282†

* Data from U. S. Bureau of Mines and Oil Weekly, Oct. 15, 1920.
† Refinery capacity under construction, Oct., 1920.

The refinery capacity of the country on January 1, 1921, classified according to refinery types as determined by the range of products turned out, is shown in detail by states in Table 44, while the figures for the country as a whole are interpreted graphically in Fig. 39. The quantitative importance of the skimming types is especially notable and the data shown illustrate the dominance of such plants under present conditions.

Relation of Capacity to Storage.—The supply of petroleum products is contingent upon refining capacity, while the ease with which the continuity of the supply is maintained is in part dependent upon the extent of storage facilities. The storage capacity in respect to gasoline is particularly important, since the demand for this product is strongly seasonal in character, being roughly twice as great in summer as in winter, and the dependence of the supply upon the activity of the skimming plant is especially marked. In periods such as the winter of 1920–21 when numbers of smaller plants shut

down, the question arises as to the probable effect upon the quantity of gasoline accumulating in storage to meet the peak demand of the coming summer.

Considerable light is thrown upon this point by Fig. 40, which shows for various parts of the country the approximate gasoline storage present in the large, medium-sized, and small refineries. This chart is based upon the gasoline actually in storage on March 31, 1920 [1] (the month when gasoline stocks are usually at their highest level); and is therefore a fairly good index of the distribution of storage capacity subsequently, since further development of storage will not substantially affect the relations shown. It is at once apparent that the gasoline storage capacity of small refineries is practically insignificant as measured against that of large refineries.

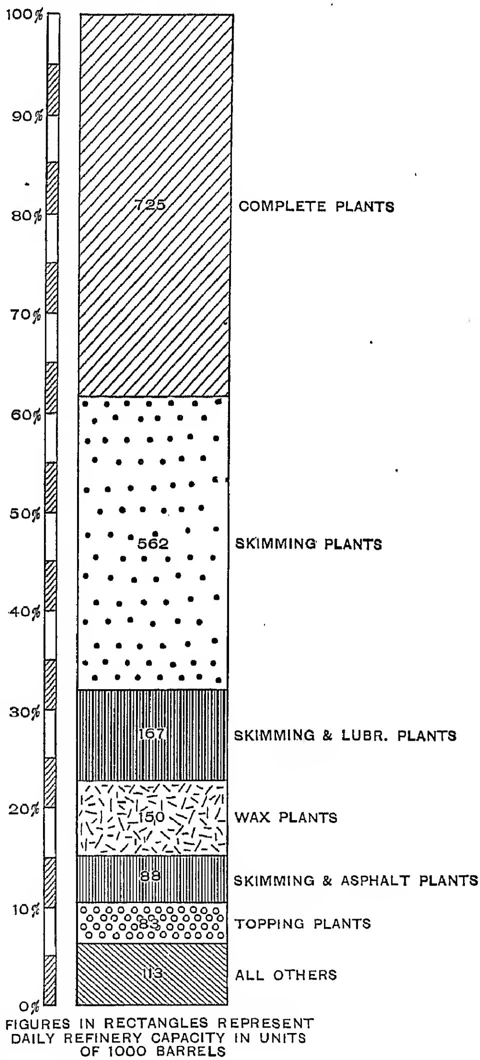


FIG. 39.—Refinery capacity of the United States on Jan. 1, 1921, classified by types of refineries; data from U. S. Bureau of Mines.

Comparison of Fig. 40 with Fig. 38, moreover, indicates that storage capacity for gasoline is roughly proportional to refining capacity, with the notable exception of the Illinois-Indiana district, where the gasoline storage vastly exceeds the normal ratio; and of California,

[1] From data supplied by H. F. Mason of the U. S. Bureau of Mines.

TABLE 44.—REFINERY CAPACITY OF THE UNITED STATES ON
Compiled from data collected
(In thousands of

State	TOPPING PLANT	SKIMMING PLANT	SKIMMING AND ASPHALT	SKIMMING AND COKE	ASPHALT PLANT	SKIM., LUB. AND ASPHALT
	Tops, Distillates, Gas and Fuel Oils	Gasoline Kerosene, Gas and Fuel Oils	Gasoline, Kerosene, Gas and Fuel Oils, Asphalt	Gasoline, Kerosene, Gas and Fuel Oils, Coke	Distillates, Gas and Fuel Oils, Asphalt	Gasoline, Kerosene, Gas and Fuel Oils, Lubricating Oils, Asphalt
Texas.......	4.75	161.85	.....	.....	15	.....
California....	59.3	56.95	20.6	.....	0.85	23.15
Oklahoma....	.....	176.8	.....	.....	.....	.....
New Jersey..	.....	.....	5.5	.....	.....	.....
Louisiana....	3	36.25	37	.....	.....	.....
Pennsylvania.	.....	1.305	.....	.....	5	10
Kansas......	.....	56.15	.....	.....	.....	.....
Wyoming....	1	20.9	.....	9.8	.....	.....
Illinois......	.....	24	.....	.....	.....	.....
Indiana......	.....	3.2	.....	.....	.....	.....
Maryland....	.....	.....	.....	.....	3	.....
New York...	.....	.....	.....	.....	.....	.....
Massachusetts	10	.....	25	.....	.....	.....
Ohio........	.....	4.6	.....	.....	.....	.....
Missouri.....	5	.....	.....	.....	.....	.....
Kentucky....	.....	8.2	.....	5	.....	.....
Rhode Island.	.....	10	.....	.....	5	.....
West Virginia.	.....	0.5	.....	.....	.....	.....
Virginia.....	.....	.....	.....	.....	5	.....
Georgia.....	.....	.....	.....	.....	.....	.....
Utah........	.....	.....	.....	.....	.....	.....
Colorado....	.....	0.05	.....	.....	.....	.....
Nebraska....	.....	1	.....	.....	.....	.....
Minnesota...	.....	.....	.....	.....	.....	.....
Arkansas....	.....	.....	.....	.....	.....	.....
Tennessee....	.....	0.5	.....	.....	.....	.....
S. Carolina...	.....	.....	.....	.....	.....	.....
New Mexico..	.....	.....	.....	.....	.....	.....
Total.....	83.05	562.205	88.1	14.8	33.85	33.15
Percentage...	4.4	29.8	4.7	.0.8	1.8	1.8

JAN. 1, 1921, BY STATES, CLASSIFIED BY TYPES OF REFINERIES
by the U. S. Bureau of Mines)
barrels per day)

SKIM., LUB. AND COKE	SKIMMING AND LUBRICATING	LUBRICATING PLANT	WAX PLANT	COMPLETE PLANT	UNCLASSIFIED		
Gasoline, Kerosene, Gas and Fuel Oils, Lubricating Oils, Coke	Gasoline, Kerosene, Gas and Fuel Oils, Lubricating Oils	Gas and Fuel Oils, Lubricating Oils	Gasoline, Kerosene, Gas and Fuel Oils, Lubricating Oils, Paraffin Wax	Gasoline, Kerosene, Gas and Fuel Oils, Lubricating Oils, Paraffin Wax, Coke, or Asphalt, or Both		Total, Jan. 1, 1921	Building, Jan. 1, 1921
.....	39.5	6.5	5.4	130	2.75	365.75	41.65
.....	52.6	....	4.2	95.5	0.2	313.35	....
.....	44.9	1.1	52.0	.....	2.0	276.8	7.5
.....	.....	....	.....	210.0	1.0	216.5	6
.....	2	1	.....	40	0.25	119.5	5
.....	11.250	0.8	29.745	59.5	...	117.6	....
12	3	....	9.5	4	...	84.65	0.2
.....	.....	....	35	.....	...	66.7	....
.....	4.3	3	.....	23.3	...	54.6	....
.....	.....	....	.....	50	...	53.2	1.2
.....	1	....	.....	38	...	42	....
.....	.....	....	1	34	...	35	....
.....	.....	....	.....	.....	...	35	....
.....	0.1	....	2.9	26.9	...	34.5	....
.....	.....	....	.....	12	...	17	....
.....	2	....	.....	.....	...	15.2	3
.....	.....	....	.....	.....	...	15	....
.....	1	....	6.2	.....	...	7.7	....
.....	.....	....	.....	.....	...	5	....
.....	4	....	.....	.....	...	4	....
.....	.....	....	4	.....	...	4	0.05
.....	0.2	....	.....	1.5	...	1.75	....
.....	.....	....	.....	.....	0.5	1.5	....
.....	1	....	.....	.....	...	1	....
.....	0.5	....	.....	.....	...	0.5	....
.....	.....	....	.....	.....	...	0.5	....
.....	.....	....	.....	.....	...	....	10
.....	.....	....	.....	.....	...	....	2
12	167.35	12.4	149.945	724.7	6.7	1888.3	76.6
0.6	8.9	0.6	7.9	38.4	0.3	100	

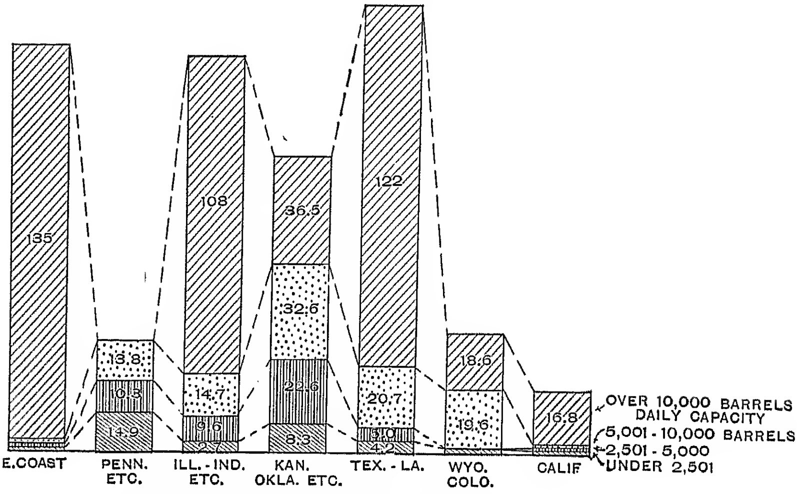


Fig. 40.—Relative storage capacity for gasoline in various parts of the country, classified by sizes of refineries; based upon quantity of gasoline in storage on March 31, 1920.

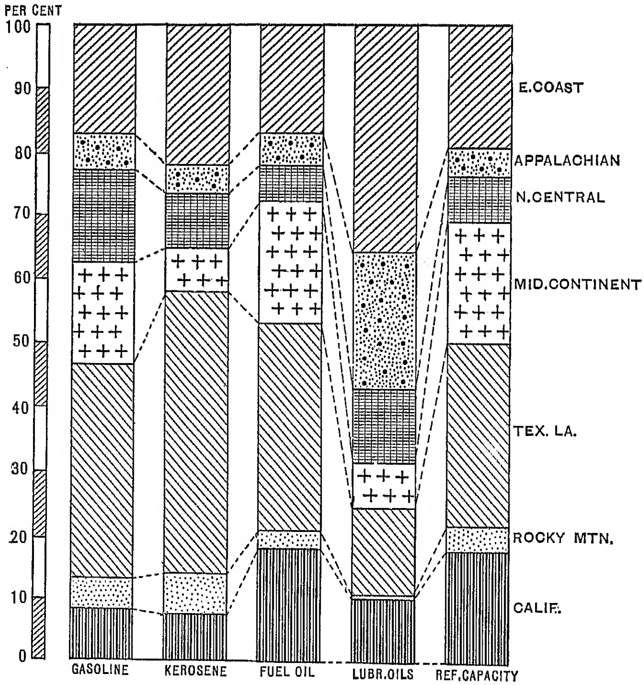


Fig. 41.—Relative storage capacity for the principal petroleum products in various parts of the country, compared with crude-still capacity; based upon figures for Oct., 1920.

where the gasoline storage falls short of the normal ratio. In the first instance, the departure from normal points to the marked degree to which Mid-Continent gasoline is stored in the north-central district; while in the second instance, the relatively low ratio of gasoline storage to refinery intake is due to the low gasoline content of California crudes, to the fact that the storage was not full at the time noted, and to the less accentuated seasonal variation of demand in that state.

The relative storage capacity in the various parts of the country for the main petroleum products other than gasoline may be inferred from the quantities of such products in storage on October 31, 1920, when stocks were large. A general view of such storage capacity, compared with refining capacity, is presented in Fig. 41, which shows with a fair measure of accuracy the conformity and discrepancy between the two.

Growth of Refining Capacity.—The growth of refining capacity over a number of years is shown in Table 45, in which the capacity for January, 1918, is called 100 and the subsequent dates are expressed in percentages of that number. (See also Table. 42.)

TABLE 52.—GROWTH OF REFINERY CAPACITY IN THE UNITED STATES, IN PERCENTAGES OF THE CAPACITY IN JANUARY, 1918

	January, 1918	January, 1919	January, 1920	January, 1921
Texas	100	109	162	188
California	100	99	109	111
Oklahoma	100	114	122	141
New Jersey	100	106	118	230
Pennsylvania	100	107	120	138
Others	100	116	136	183
Whole country	100	109	129	159

The table shows the notable degree to which refinery installations developed in 1919 and 1920, particularly in Texas and New Jersey. The refinery capacity of the entire country increased 18 per cent during 1919, and 23 per cent in 1920, with an additional capacity under construction at the beginning of 1921 amounting to 4 per cent of the total. It would seem that refinery capacity, in common with many lines of activity, overexpanded in the boom period following the armistice, and hence faced the 1920–1921 period of business liquidation in an inflated condition. The effect of the rapid exploita-

tion of the Texas oil-fields is reflected in refinery installations in that state, while the growing quantity of Mexican oils imported into the United States is partly responsible for the increased capacity in New Jersey.

Refining Capacity Utilized.—For a number of years only about three-quarters of the installed refining capacity of the country has been actually utilized, which reflects in further degree the over-

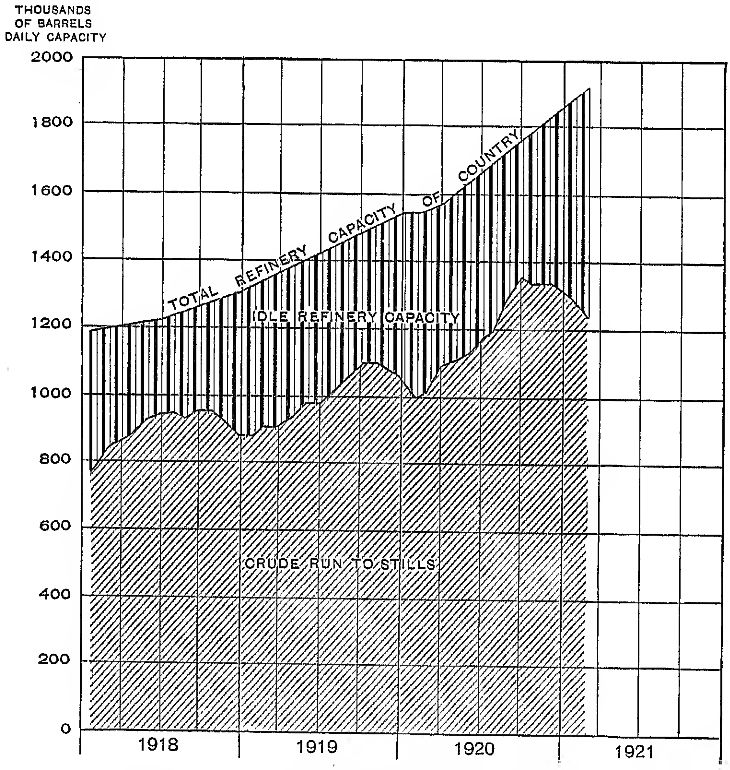


FIG. 42.—Used and unused refinery capacity of the United States by months, 1918–1921; data from U. S. Bureau of Mines.

expanded condition in which the oil-refining industry found itself when the period of rapid expansion was terminated by the business depression in 1920. The unused, or idle, refinery capacity in the United States by months, 1918–1921, is shown graphically in Fig. 42, prepared from data published by the U. S. Bureau of Mines as given in Table 46.

The unused refinery capacity in various parts of the country in October, 1920, when refining operations were unusually vigorous, is

TABLE 46.—OPERATING AND IDLE REFINERY CAPACITY OF THE UNITED STATES BY MONTHS, 1918–1921

(Data from U. S. Bureau of Mines *)

Date	Refineries Operated			Total Number of Refineries		Idle Equipment	
	No. of Plants	Daily Capacity of Plants Operated (In Thousands of Barrels)	Daily Crude Run of Plants (In Thousands of Barrels)	No. of Plants	Total Daily Capacity of All Plants (In Thousands of Barrels)	No. of Idle Plants	Total Idle Capacity of All Plants (In Thousands of Barrels)
1918. January..	245	1158	769	....	1190	....	421
February.	....	......	835	....	......	....	......
March...	....	......	846	....	......	....	......
April....	....	......	873	....	......	....	......
May.....	....	......	920	....	......	....	......
June.....	....	......	938	....	1218	....	......
July.....	....	......	941	....	......	....	......
August...	....	......	920	....	......	....	......
September	....	......	946	....	......	....	......
October..	....	......	943	....	......	....	......
November	....	......	914	....	......	....	......
December	267	1226	870	289	1295	22	425
1919. January..	....	......	870	....	......	....	......
February.	....	......	901	....	......	....	......
March...	277	1243	899	....	......	....	......
April....	....	......	926	....	......	....	......
May.....	....	......	976	....	......	....	......
June.....	....	......	964	....	......	....	......
July.....	....	......	1007	....	......	....	......
August...	287	1277	1044	....	......	....	......
September	....	......	1087	....	......	....	......
October..	290	1338	1087	....	......	....	......
November	....	......	1074	....	......	....	......
December	292	1356	1046	373	1531	81	485
1920. January..	....	......	994	373	1531	....	537
February.	....	......	1007	....	......	....	......
March...	265	1560	1084	....	......	....	......
April....	....	......	1095	....	......	....	......
May.....	....	......	1115	....	......	....	......
June.....	307	1601	1164	....	1593	....	429
July.....	311	1637	1194	....	......	....	......
August...	322	1671	1283	....	......	....	......
September	324	1675	1352	....	......	....	......
October..	332	1687	1312	....	......	....	......
November	326	1698	1315	....	......	....	......
December	328	1714	1306	....	......	....	......
1921. January..	311	1721	1279	415	1889	104	610
February.	291	1692	1235	....	......	....	......
March...	290	1697	1145	....	......	....	......
April....	299	1747	1253	....	......	....	......
May.....	302	1739	1193	....	......	....	......
June....	310	1760	1231	....	......	....	......

* Compiled in part by M. C. Ehlen.

given in Fig. 43, where the unused capacity may be seen to have been much greater in the southwest than in the eastern and the northcentral states.

The unproductive capital tied up in the idle equipment is worthy of emphasis, as well as the poor prospects for financial success enjoyed by new and improperly located ventures in the face of the conditions depicted. The high production costs of products flowing through plants running short of full capacity are not sufficiently recognized, owing to cost accounts that fail to measure this factor; but, as pointed out by Gantt, Polakov, and other industrial engineers, this matter is a potent cause of financial loss and even failure, and should receive the closest attention and study.

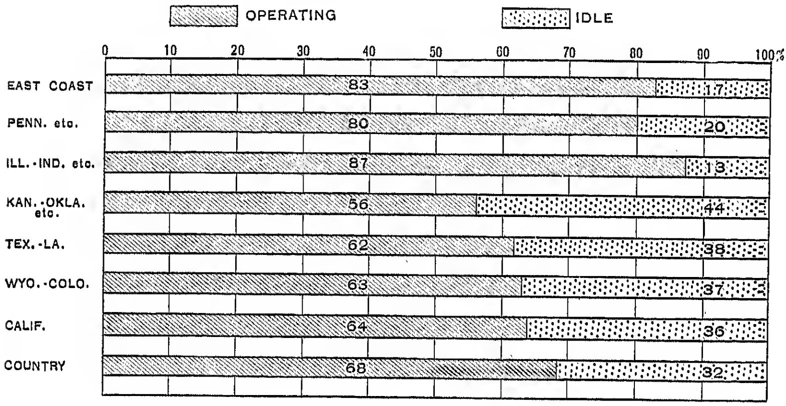


FIG. 43.—Proportion of installed refinery capacity in use in Oct., 1920, in various parts of the country; data from U. S. Bureau of Mines and Oil Weekly.

Conclusions.—The foregoing analysis of refinery capacity affords quantitative evidence for a number of deductions that are fairly well known qualitatively; namely, that refinery capacity is considerably greater than the needs of the country; that much of this capacity is poorly located for survival; that a notable percentage of the capacity is of the skimming or incomplete-run type and hence poorly adapted for profitable operation with high cost crudes; that the installation of refinery capacity enjoyed an accelerating growth well into the period of industrial depression; and that the oil-refining industry as a whole is handicapped by idle capital investment to the extent of unused refinery capacity.

Projected into the future, these conditions spell considerable readjustment in the refinery situation; first, as a result of the period of business liquidation of 1920–1921; and, second, as a result of the stringency in domestic crude supply that is due to follow.

On the whole, it is apparent that the refinery situation reflects in no uncertain terms the peculiar economic conditions surrounding the production of crude petroleum; small, incomplete refineries spring up in proximity to flush production only to die again as the wave of oil-field development passes on. The growth of refinery capacity has apparently been influenced more by supply than demand; the future, it would seem, will dictate a closer-knit coordination with all the economic factors involved through a process of elimination that will affect developments projected without due regard to these considerations.

CHAPTER VIII

THE OUTLOOK FOR OIL REFINING

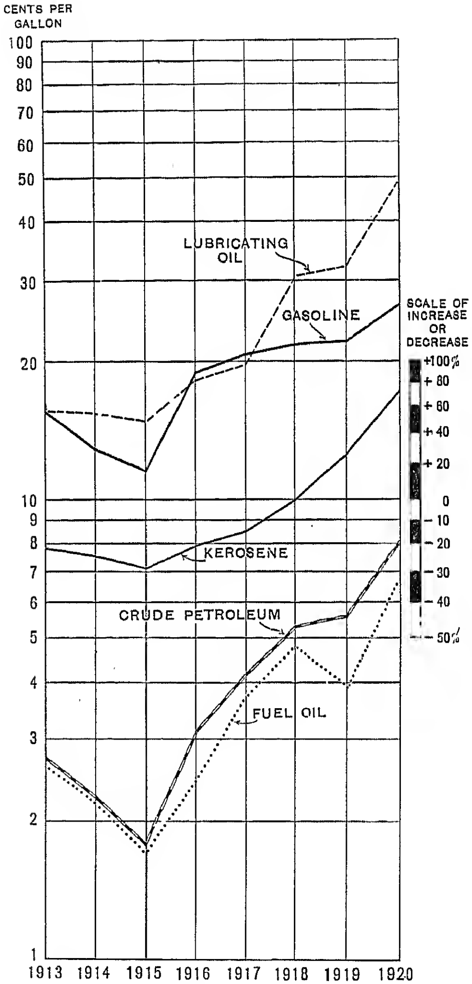


FIG. 44.—Trend of the average prices of crude petroleum and its principal products in the United States by years, 1913–1920.

CONDITIONS are gradually developing in the oil situation under which those refineries running domestic crudes, which are not prepared to operate as plants turning out lubricating oils, will have to go out of business as unprofitable enterprises. This deduction is based upon the trend of prices and values as revealed during the eight-year period, 1913–1920, the continuation of which, following the industrial depression of 1921, is predicated upon the growing inability of the domestic output of crude petroleum to meet the country's requirements.

Trend of Prices, 1913-1920.[1]—The course of market conditions for crude petroleum and its principal products for 1913–1920 is shown graphically in Fig. 44, in which the slopes of the five curves indicate the direction and intensity

[1] A fuller discussion of prices is given in Chapters 17 and 18, which should be consulted in the present connection.

of the economic forces at work. The outstanding feature of the chart is the marked advance over the past few years in the price of lubricating oils contrasted with the relatively moderate rate of increase in the price of gasoline. The advances in the prices of crude petroleum, fuel oil, and kerosene are intermediate in degree between lubricating oils, on the one hand, and gasoline, on the other, though tending to approach the former. The differential changes in prices of the four major joint-products of crude petroleum are of great importance, for they indicate corresponding changes in the conditions under which oil-refining may be profitably conducted.

The trends shown in Fig. 44 will not maintain themselves through the price depression of 1921, but revealing the habit of oil prices on a rising market they may be expected to reassert themselves when oil prices next begin to advance under pressure from the crude petroleum situation.

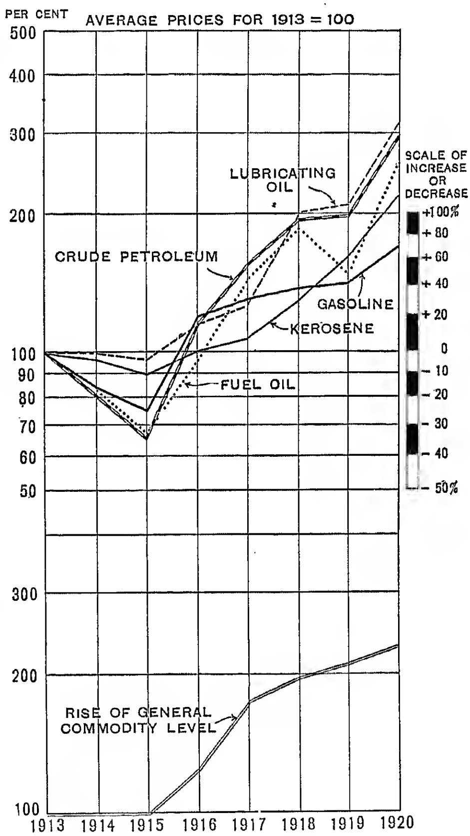


FIG. 45.—Trend of the price levels of crude petroleum and its principal products in the United States by years, 1913–1920, in percentages of the average prices in 1913.

Two Types of Prices.—The prices of lubricating oils and fuel oil are determined in a highly competitive market by the normal operation of supply and demand, whereas the prices of gasoline and kerosene are to a dominant degree decided by the tank-wagon price set for these products by large marketing companies. This fundamental distinction between the two groups of prices should be held clearly in mind as it is an important key to the course of prices in the future. In short,

the one set of prices is quite sensitive to the vagaries of the market, while the other set of prices is open to additional influences with a stabilizing result.

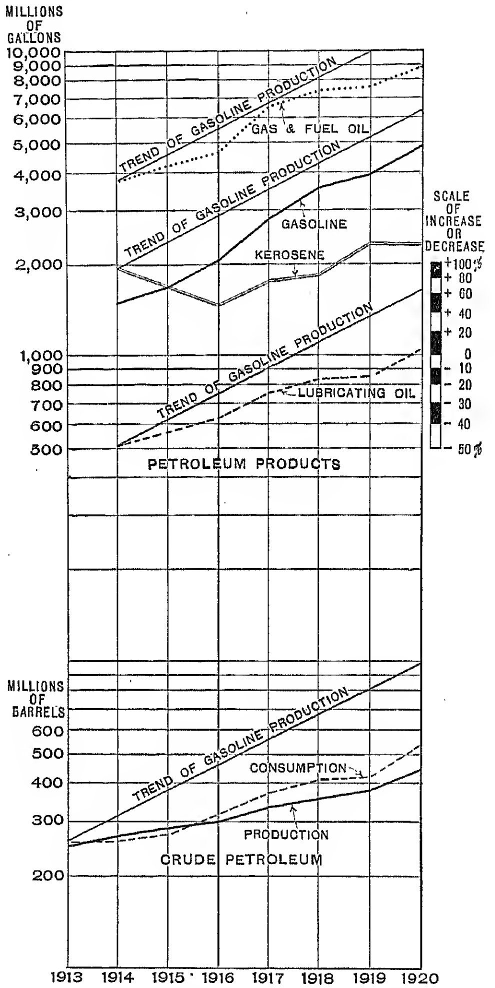


Fig. 46.—Trend of the output of crude petroleum and its principal products in the United States, 1914–1920, compared with the trend of gasoline production.

Fig. 45 illustrates the extent to which the prices of crude petroleum and its principal products increased between the pre-war year of 1913 and 1920. It will be observed from this chart that the prices of lubricating oils and fuel oil, together with crude petroleum, rose to higher levels than the prices of kerosene and gasoline, the last named having advanced the least of all. This relationship is significant and suggestive of the fundamental difference existing between the two sets of prices. For purposes of comparison, the price level of commodities in general is also entered upon Fig. 45, and it may be observed that this index line, if superimposed upon the price curves, will divide them into the two fundamental groups already noted.

The Stress Product.—Although gasoline has advanced in price in less degree than the other petroleum products, it may be mathematically demonstrated (see Fig. 46) that a greater discrepancy between supply and demand has developed in respect to gasoline

than in regard to the other petroleum products. Fig. 46 shows the trend in output of the four major petroleum products, together with the trend in production and consumption of crude petroleum. The straight line indicating the average trend of gasoline production is fitted to the curves showing the trend of production of fuel oil, kerosene, lubricating oils, and crude petroleum. The angle between the average trend line of gasoline production and the trend lines of these other products indicates that the demand for gasoline is the major economic force sending the oil industry forward. It is observable that the gasoline demand is notably stronger than the supply of crude petroleum, even if imports of crude petroleum are added to the domestic production, and in consequence a marked lagging in the output of fuel oil and kerosene is taking place in order to compensate for the discrepancy. It is a striking fact that the petroleum product which has been enjoying the strongest demand is the one which underwent the slightest price advance.

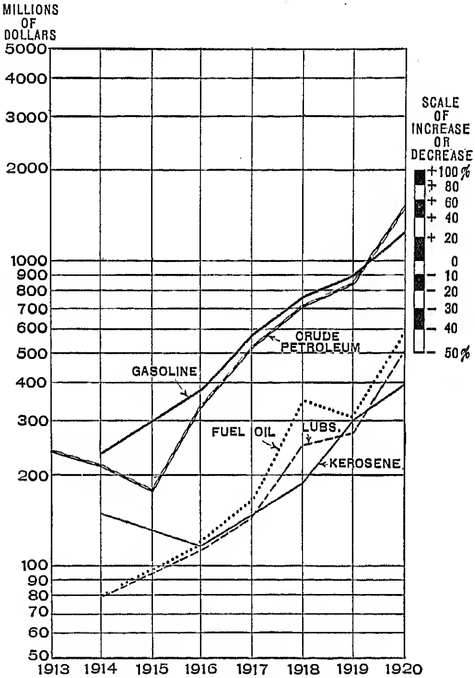


Fig. 47.—Trend of the value of the domestic output of crude petroleum and its principal products by years, 1914–1920.

The Profit Product.—The growth in value of the total quantity of crude petroleum and its principal products produced in this country over the past few years is shown in Fig. 47. The close coincidence of gasoline and crude petroleum should especially be noted. The interpretation of this chart becomes clearer if the following relationships, which are not commercially correct, but in an economic sense are true, are accepted as valid, namely: that gasoline receipts pay for the raw material; kerosene receipts pay for refining; and fuel oil receipts pay for marketing, leaving the receipts from lubricating oils as profit. Referring to Fig. 47 in detail, it will be observed that the cost of

domestic crude in 1920 exceeded the value of gasoline produced, a circumstance throwing a greater burden upon the other products. A close coincidence in values is to be observed for fuel oil, kerosene, and lubricating oils.

In view of this chart, and in the light of events in the refining industry, the conclusion is offered that skimming plants are profitable only in periods of flush production and many of these enterprises have already found it unprofitable to continue in business. Refineries of intermediate character are next in line to feel a continuation of the type of stress already affecting skimming plants. Only lubricating plants, therefore, will remain as the logical survivors of a continuation of the present competition, which, it should be observed, is operating not only between industrial units, but between the economic forces at play in the fashion pointed out above. Many refineries not making lubricating oils, therefore, under the conditions lying ahead may be expected to show no profits and in consequence to fail.

Why Gasoline Prices will Continue to Lag.—A change in the course of gasoline prices in the direction of accelerated rise in level, would obviate the consequence otherwise in store for the economically inefficient refinery. Gasoline prices, however, may not be logically expected to show a departure from their past performance. This product has come into such universal use and touches the public at so many points that it has essentially become a public utility in an economic sense. The surmise is made that this fact is not only recognized but has been acted upon by the marketing companies setting the price pace for gasoline; and the price has been tempered accordingly. But this deduction does not rest alone upon surmise. Figs. 44–46 are presented in support of this theory. In no other way could a stress product show the mildest advance in price amongst its fellows.

Why Non-lubricating Refineries will Fail.—Fig. 48 shows the increase in value of the main petroleum products over recent years compared with the cost of the domestic crude petroleum entering into their fabrication. Imported crude petroleum and minor petroleum products do not appear on the chart because of the lack of statistical data, but these groups approximately balance, and the chart presents the true situation as it stands. The price of domestic crude petroleum in the long run will continue to advance (irrespective of minor fluctuations immediately ahead) and the price of gasoline will also continue to lag in its advances behind the prices of its joint-products. The condition developing in 1920 and shown in Fig. 48, where gasoline and most of the kerosene are necessary to support the cost of crude, leaves little margin of profit for plants not making

lubricating oils. This differential is decreasing under the influences of the forces gathering impetus in the situation, and within a very few years the failure of refineries which are running domestic crude,

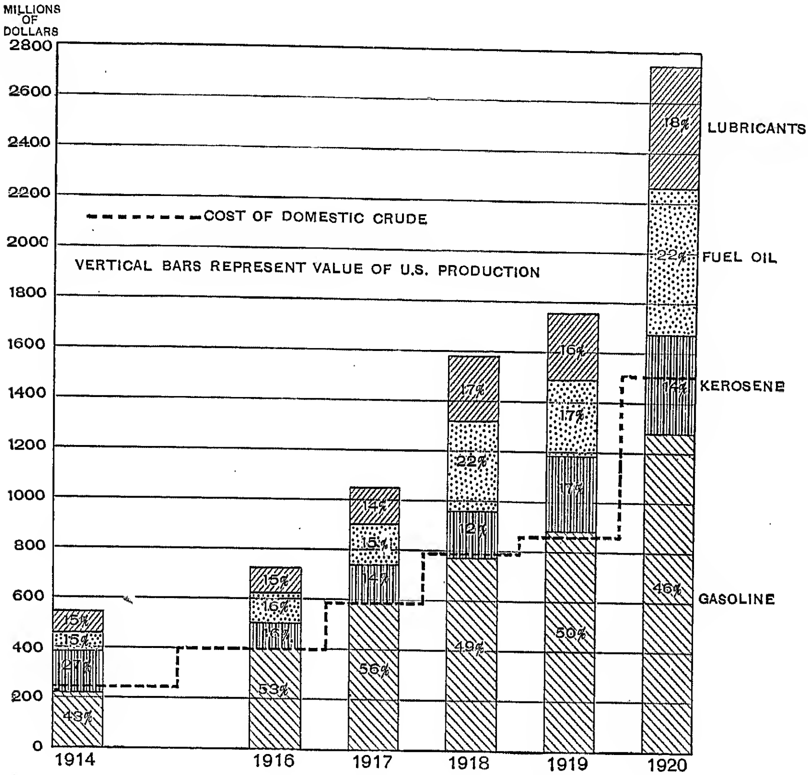


FIG. 48.—Comparison of the relative importance of the principal petroleum products as sources of revenue to the oil industry, 1914–1920, contrasted with the cost of crude petroleum.

but are inadequately equipped for extracting the full range of values from their raw material, may be expected to be widespread.

CHAPTER IX

GASOLINE

GASOLINE cannot be commercially manufactured as a single product, since its production involves the output of at least two other products, kerosene and fuel oil. Gasoline, in consequence, is a joint-product of crude petroleum, and its whole economic status is colored by this circumstance.

Before the advent of the automobile, the production of kerosene in growing quantity necessitated the output of more gasoline than could be absorbed by the small market for this product; gasoline was then troublesome to dispose of and state inspection laws were passed to prevent the adulteration of kerosene with gasoline. With the rise of automotive transportation, however, the demand for gasoline soon exceeded that for kerosene, thus reversing the relationship of the two products. Now the production of kerosene is incidental to the manufacture of gasoline, and there is a growing tendency for the light components of kerosene to be included in the gasoline turned out, so insistent is the demand for the latter; although state inspectors are still maintained at public expense to keep the gasoline out of kerosene.

The commercial supply of gasoline is composed of natural, or straight-run, gasoline; a volatile gasoline won from natural gas; synthetic gasoline made by " cracking " heavier petroleum distillates; and naphthas which alone would rank as light kerosene.

Natural Gasoline.—Natural gasoline, also known as straight-run gasoline, is made up of the components of crude petroleum that distil off at relatively low temperatures. A few years ago, natural gasoline was the only type of gasoline on the market and for that reason is still commonly believed to be the best type obtainable. Many automobile users have been educated to demand straight-run gasoline, and feel that the more common blended varieties are inferior substitutes. As a matter of fact, however, the greater part of the gasoline marketed to-day is some sort of blend and " many of the blended products are preferable to straight-run products, particularly if the added constituent is so-called 'casing-head' gasoline derived from natural gas."[1]

[1] Hill and Dean, Quality of Gasoline Marketed in the United States, Bull. 191, U. S. Bureau of Mines, 1920, p. 5.

Natural-gas Gasoline.—Between 1910 and 1920 a rapidly increasing and significant yield of gasoline has been attained through the recovery of a highly volatile gasoline from natural gas, which has been blended with straight-run gasoline or with distillates too heavy to rank alone as gasoline. The raw product is commonly called casing-head gasoline[1] and it enlarges the gasoline supply to a greater extent than its actual volume, since its employment renders available for motor use considerable quantities of distillates that in their original state lacked a large enough proportion of low-boiling constituents to make satisfactory motor-fuels.

Because of the cheapness with which casing-head gasoline could be won as a by-product from natural gas, and the scope for expansion offered by the field, the growth of the casing-head gasoline industry has been rapid. In 1920 casing-head gasoline was responsible for around a tenth of the country's total gasoline output. The growth of this contribution, however, has begun to slacken, and a general survey of the natural gas situation would seem to indicate that contributions from this source have already reached approximately 50 per cent of their ultimate capacity. Developments pointing to the same conclusion are to be found in the fact that the casing-head gasoline industry grew up on the basis of the compression process which extracts gasoline from "wet" gas heavily laden with gasoline vapor, whereas attention is now turning in growing degree to the leaner so-called dry gas which requires a more intimate absorption process to yield results.

Cracked Gasoline.—A growing quantity of gasoline is manufactured from heavy petroleum fractions by processes of cracking distillation, whereby the heavy hydrocarbons are decomposed or "cracked" into lighter, more volatile components approximating straight-run gasoline in performance. Cracked gasoline is not used as such, but is blended with straight-run gasoline and casing-head gasoline to make a commercial product. Most of the cracked gasoline is made by the Burton process, developed and controlled by the Standard Oil Company of Indiana, but leased by this organization to certain other companies. The total quantity of cracked gasoline now produced is not definitely known, but in 1918 the output was approximately 360 million gallons, or about one-tenth of the country's total production of gasoline, a ratio which probably obtained with little change in 1920.

[1] In 1921, manufacturers of gasoline from natural gas formed an "Association of Natural Gasoline Manufacturers" and adopted the trade name "natural gasoline" to supersede "casing-head gasoline" for gasoline made from natural gas. As used in this book, however, natural gasoline designates gasoline won from petroleum by straight refining.

Changing End-point of Gasoline.—Gasoline is not a single chemical product possessing definite properties, but is a series of related compounds running from hydrocarbons with small, light molecules to hydrocarbons of larger and heavier molecular character. Gasoline, therefore, is a chain of compounds ranging from light, highly volatile components through graded intermediates to relatively heavy, less volatile end-products. The character of the compounds at the light and heavy ends of the series is fixed at any given moment by the dictates of commercial practice and economic requirements, but in a manner that may be correlated with the conditions of supply and demand governing the production of gasoline.

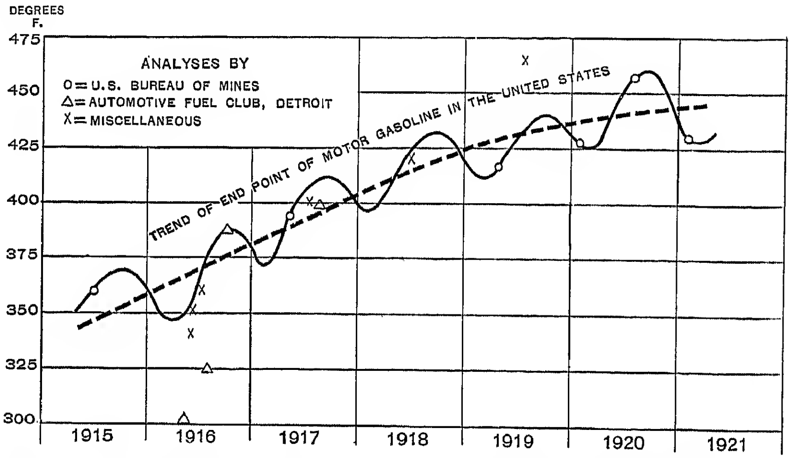


Fig. 49.—Hypothetical curve showing the trend and seasonal fluctuation of the average end-point of motor gasoline in the United States, 1915–1921, based mainly on surveys made by the U. S. Bureau of Mines.

The character of a given type of gasoline is determined chemically by subjecting a sample to a standard method of distillation and noting the boiling point of the first tenth, the second tenth, and each subsequent tenth of the sample as it distils off, with special reference to the initial point and the end, or dry, point of the process. The series of temperatures so determined is then plotted on cross-section paper as a curve which gives a picture of the volatility range of the sample. This distillation curve expresses the character of the gasoline in terms of its suitability as motor-fuel, since the initial point indicates the readily vaporized components that determine the ease with which the engine may be started, while the end-point measures the extent to which heavy components are present that tend to pass through the engine incompletely burned. The U. S. Bureau of Mines makes periodic surveys of the gasoline supply, subjecting to distillation

scores of samples collected in all parts of the country; the results yield average curves for the various sections of the country and for the country as a whole which permit the trend of the supply to be definitely determined.

For a number of years, and particularly since 1915, the end-point of gasoline has been tending upward, that is, the volatility of gasoline has been decreasing. An indication of the extent to which this has been taking place is given in Table 47, in which the results of distillation tests in successive years are brought together.

TABLE 47.—THE RISING END-POINT OF GASOLINE, 1910–1921

Year	No. of Samples	Locality of Samples	End-point
1910. January *...............	1	....	278 F.°
1915. Second half †............	Typical	....	360° F.
1916. April ‡..................	1	Detroit	300° F.
July ‡..................	1	Detroit	325° F.
September ‡............	1	Detroit	390° F.
1917. April, May §............	247	Whole country	394° F.
July‡	1	Detroit	400° F.
1919. April ¶..................	81	Leading cities	417° F.
April, May §............	851	Whole country	423° F.
1920. January ¶...............	81	Leading cities	427° F.
July ¶..................	82	Leading cities	456° F.
1921. January ‖...............	115	Leading cities	429° F.

* F. H. Floyd, Commercial Gasoline and the Impurities That Are Being Encountered, Soc. Aut. Eng., Jan., 1911.

† Rittman, Jacobs, and Dean, Physical and Chemical Properties of Gasolines Sold throughout the United States during the Calendar Year, 1915, Tech. Paper, 163, U. S. Bureau Mines, 1916.

‡ Automotive Fuel Club, Detroit, Mich.

§ Hill and Dean, Quality of Gasoline Marketed in the United States, Bull. 191, U. S. Bureau of Mines, 1920.

¶ N. A. C. Smith, Motor Gasoline Survey, U S. Bureau of Mines, Reports of Investigations, July, 1920.

‖ N. A. C. Smith, Third Semi-annual Motor Gasoline Survey, U. S. Bureau of Mines, Reports of Investigations, February, 1921.

The end-point figures given in Table 47, some of which are averages for the entire country, form a basis for interpreting the change in volatility of the country's gasoline supply over a period of recent years. The data are accordingly interpreted in Fig. 49, which shows

that the end-point has been consistently rising between the years 1915 and 1921, but with a marked seasonal fluctuation. The seasonal fluctuation shown is based partly on distillation data and partly on observation and inference as to the seasonal relation between gasoline and kerosene, the peak of the gasoline demand coming in late summer and tending to draw the light kerosene ends into the gasoline supply, with the peak of kerosene requirements falling in the winter off-season for gasoline and reversing the tendency. The seasonal variation is likewise suited to the operating conditions of the engine, since the heavy ends are more readily converted into power under summer conditions than in the winter.

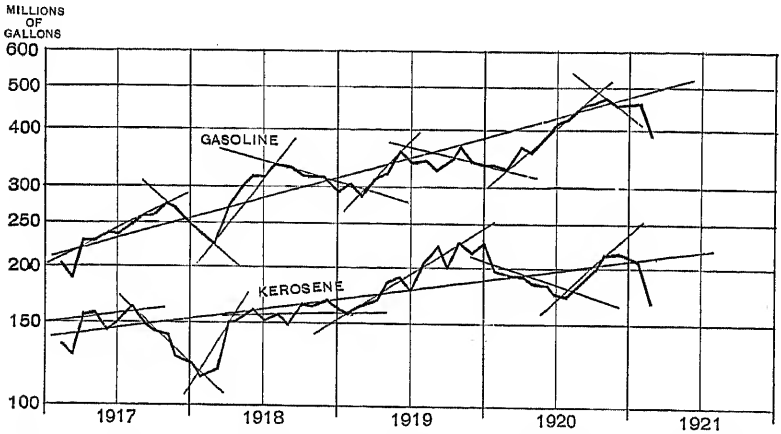


FIG. 50.—Trend of the output of gasoline and kerosene in the United States by months, 1917–1920, showing the diverging secular and complementary seasonal relationship between the gasoline and kerosene supply. When the two curves are converging, the end-point of gasoline is declining, and when the two curves are diverging the end-point of gasoline is rising.

The complementary tendency in the relationship between gasoline and kerosene is shown in Fig. 50, in which the productions of gasoline and kerosene by months for the period 1917–1920 are plotted on a semi-logarithmic scale and straight trend lines fitted to the two curves as a whole and to the component parts of the two curves. It is apparent, in the first place, bearing in mind that the two products are made dominantly from the same raw material, that the output of gasoline has been increasing much more rapidly than the output of kerosene, suggesting the tendency for the light kerosene ends to be progressively included in the gasoline supply. In the second place, it may be observed that the respective curves for gasoline and kerosene tend roughly to diverge in the spring and to converge in the fall, pointing to a seasonal swing on the part of the light kerosene ends

from kerosene to gasoline, and back again as the season progresses. This seasonal relationship is not sharply defined throughout the years charted, but such departures from this tendency as appear arise from the influence of the conditions of supply and demand, an oversupply of gasoline or an undersupply of kerosene tending to reverse the normal seasonal proclivity. Thus in 1919 the relative abundance of the gasoline supply coupled with the reopening of the far-eastern markets for kerosene injected counter forces that modified the seasonal reflex. On the whole, however, the various factors can be closely enough measured to permit the character of the gasoline supply to be projected ahead and the end-point to be anticipated, yielding results of practical value to the oil producer and oil marketer, as well as to the interests concerned in the design and modification of the automotive power plant.

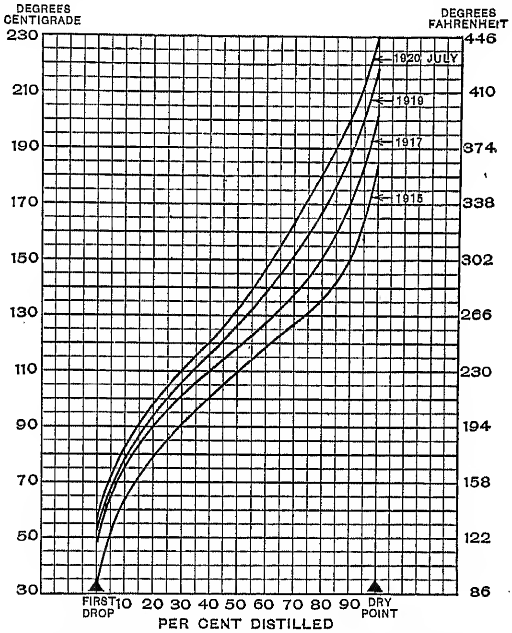


Fig. 51.—Trend of the change in volatility of gasoline, 1915–1920, showing the rise in end-point; after R. E. Fielder, Society of Automotive Engineers; data from U. S. Bureau of Mines.

Thus far in this section emphasis has been laid upon the behavior of the end-point, since this characteristic is the key to the character of the gasoline supply. In specific problems, however, the whole distillation curve is important, although the various components of the supply display a tendency to behave in conformance with the change in end-point, as indicated in Fig. 51, which shows the distillation curves for the average gasoline in use over a number of years.

The cause of the rising end-point of gasoline does not seem to be comprehended in all quarters. While doubtless the result of attempts to adulterate the gasoline supply in some specific instances, the change in general is undoubtedly an economic response to a demand that is outdistancing supply and forcing modifications in the char-

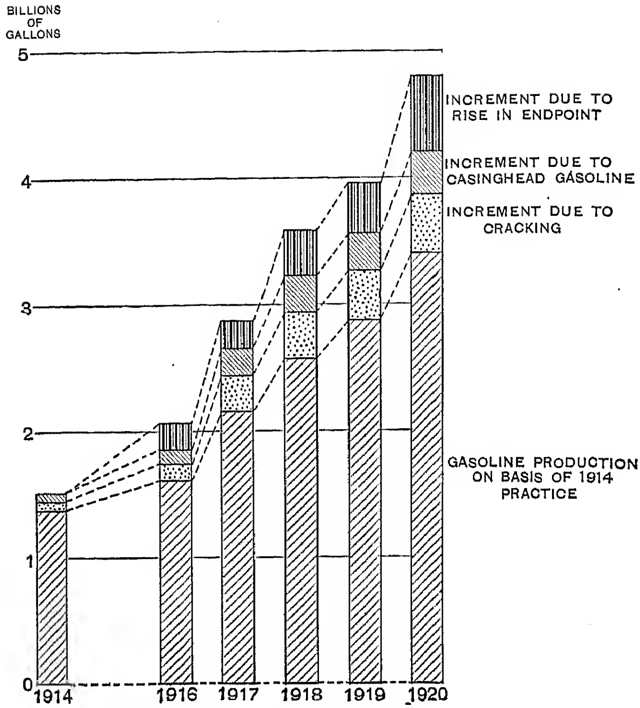


FIG. 52.—The economic components of the gasoline production of the United States, 1914–1920.

acter of the supply. With the end-point of 1914, for example, the gasoline supply of 1920 would have fallen some 10 per cent short of meeting the requirements of the market.

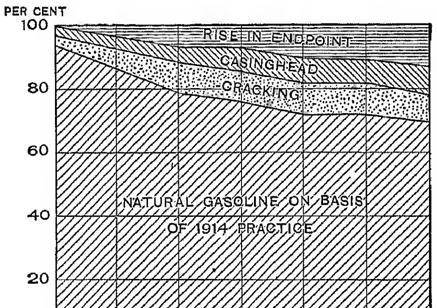


FIG. 53.—Trend of the gasoline supply of the States, 1914–1920, showing relative importance of the several components.

The end-point of gasoline has a fundamental bearing upon automotive transportation, which is treated in further detail in Chapter 22.

Components of the Gasoline Supply.—The gasoline supply, as already noted, is composed dominantly of natural, or straight-run, gasoline, supplemented in recent years by a growing volume of

cracked gasoline, casing-head gasoline, and heavy ends, the last mentioned being reflected in a rising end-point. The three supplementary types of gasoline develop in a measure together since no one is marketed alone but goes into use in blended form. Casing-head gasoline and heavy ends are particularly complementary.

The relative contributions made by the various components of the gasoline supply cannot be determined with close accuracy, because of the absence of exact statistics; but an interpretation based upon available figures and estimates, checked by economic reasoning, is given in Fig. 52, which indicates the growing degree to which the gasoline supply is becoming dependent upon the supplementary contributors. The same data, converted into percentages, are presented in Fig. 53, as emphasizing the trend of the situation.

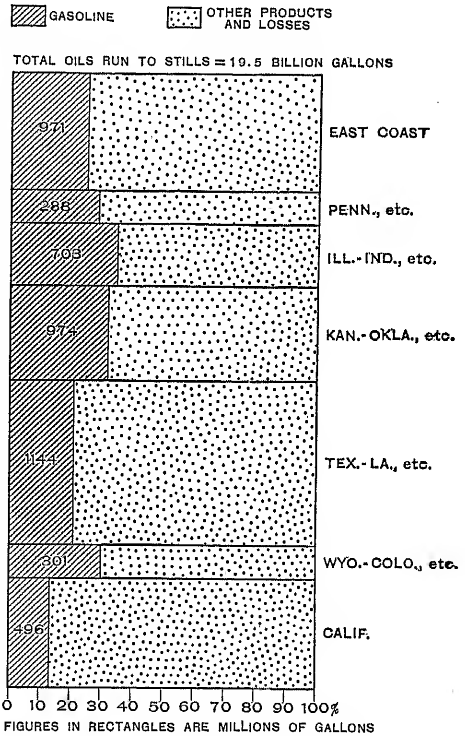


FIG. 54.—The production of gasoline in the United States in 1920, by refinery districts.

Sources of Supply.—The production of gasoline is fairly well distributed in reference to the location of demand, although a considerable volume is transported from the south-central states to the more populous areas to the north and northeast. The quantity produced in the various refinery districts of the country in 1918, 1919, and 1920, together with the percentage yields in respect to the total oils run to stills, is shown in Table 48, the figures for 1920 being interpreted graphically in Fig. 54.

Current Trend of Supply and Demand.—The trend of the major factors entering into the interplay between supply and demand is shown by months for the period 1917–1921 in Fig. 55. The data are plotted on a semi-logarithmic, or ratio, scale in which the slopes of

the lines are proportional to the percentage changes; thus the various factors charted are directly comparable and the effect of a change in any one item upon the other items may be observed and analyzed. The chart is presented not only as an interpretation of current developments, but as a suggested means for keeping track of conditions ahead, since the data are readily obtainable from month to month for posting on an original chart similarly designed.

TABLE 48.—PRODUCTION OF GASOLINE IN THE UNITED STATES BY REFINERY DISTRICTS, 1918–1920

Refinery District	1918		1919		1920	
	Production in Millions of Gallons	Per Cent of Total Oils Run to Stills	Production in Millions of Gallons	Per Cent of Total Oils Run to Stills	Production in Millions to Gallons	Per Cent of Total Oils Run to Stills
East Coast.........	719	24.0	780	22.8	971	25.2
Pennsylvania.......	242	27.8	270	28.4	288	29.3
Illinois, Indiana....	461	36.5	571	34.6	703	35.4
Kansas, Oklahoma..	865	29.4	881	30.8	979	32.2
Texas, Louisiana....	637	17.4	800	20.1	1144	21.7
Wyoming..........	212	30.5	238	28.4	301	30.1
California..........	434	12.9	418	12.3	496	14.4
Total...........	3570	22.6	3958	23.0	4882	25.0

The outstanding features of Fig. 55 are: The upward trend of production; the marked complementary relationship between domestic consumption and stocks, reflecting the highly seasonal character of the gasoline demand; the failure of the successive peaks of the stocks curve to show an upward trend paralleling that of production; and the strongly fluctuating character of the exports curve.

A statistical summary of the gasoline situation, upon which Fig. 55 is partly based, is given in Table 49.

Relation of Production to Stocks.—The size and trend of production by months, compared with the stocks of gasoline on hand, in the various refinery districts in the United States for 1919 and 1920, are shown graphically in Fig. 56 based on data given in Table 50. The chart brings together in one comparable view the refinery statistics for gasoline in a form suitable for drawing deduction as to

the variations in supply and demand in various parts of the country. As with Fig. 55, the type of chart is presented as a practical method of interpreting a extensive range of statistics difficult to analyze in tabular form.

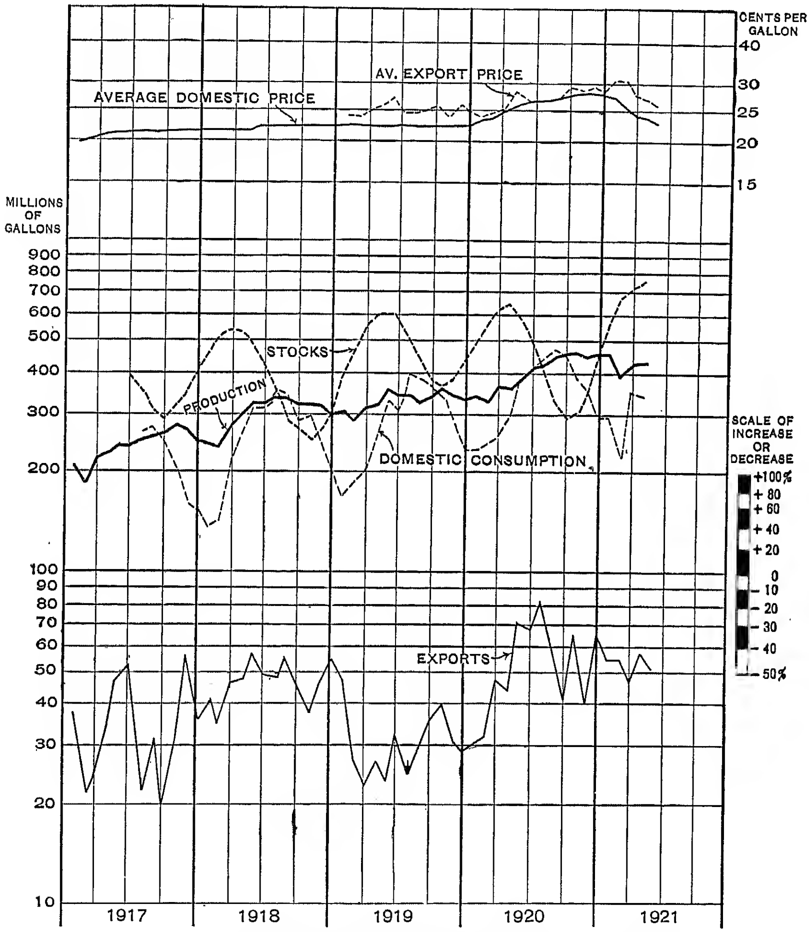


FIG. 55.—Trend of the gasoline situation in the United States by months, 1917–1921.

A notable feature of the chart is the seasonal demand reflected by the valleys in the curves for stocks, stressing the importance of the seasonal factor in the marketing of gasoline.

Demand for Gasoline.—The demand for gasoline during the past decade has not only grown tremendously, but its character has also changed notably, in response to the requirements of automotive

TABLE 49.—SUMMARY OF THE GASOLINE SITUATION

Period	Production, Millions of Gallons	Stocks,* Millions of Gallons	Exports, Millions of Gallons	Domestic Consumption, Millions of Gallons	Average Domestic Price (Tank-wagon), Cents per Gallon	Average Export Price, Cents per Gallon
By years, 1914	1500	....	210	....	13.0	12.0
1915	....	....	282	....	11.7	12.0
1916	2059	....	356	....	18.9	19.3
1917	2851	412	416	....	20.6	22.4
1918	3570	297	559	3129	21.7	25.0
1919	3958	447	372	3436	22.2	24.7
1920	4883	462	635	4256	26.5	27.2
By months:						
1919. January	304	383	48	170	22.5	23.8
February	284	458	27	182	22.2	23.6
March	311	546	22	201	22.2	24.9
April	320	594	28	245	22.2	25.3
May	354	594	26	327	22.2	27.0
June	338	594	32	306	22.3	24.1
July	342	515	25	397	22.2	24.1
August	327	435	30	378	22.2	24.8
September	340	371	37	367	22.2	25.4
October	363	354	41	340	22.2	23.9
November	339	378	31	284	22.2	26.0
December	336	447	29	238	22.2	24.7
By months:						
1920. January	337	516	31	237	23.1	23.8
February	323	563	32	244	23.8	24.5
March	367	626	47	257	25.1	24.6
April	356	644	44	295	25.9	28.6
May	381	578	69	378	26.3	26.7
June	415	504	69	420	26.8	27.0
July	423	413	82	432	26.8	27.2
August	444	323	59	475	27.5	27.4
September	454	288	40	449	28.2	29.3
October	466	301	65	388	28.2	28.9
November	453	355	40	359	28.1	29.5
December	464	462	65	292	28.0	28.6
By months:						
1921. January	460	572	55	295	27.6	30.8
February	388	681	54	225	25.0	30.7
March	420	713	47	341	24.0	27.4
April	426	747	57	335	23.5	26.6
May	449	800	41	355	22.0	25.2
June	430	751	39	440	21.4	24.0

* End of period.

transportation. At the present time the volume of gasoline consumed by passenger automobiles, trucks, and tractors, and going into the export trade, constitutes over 90 per cent of the supply, the uses

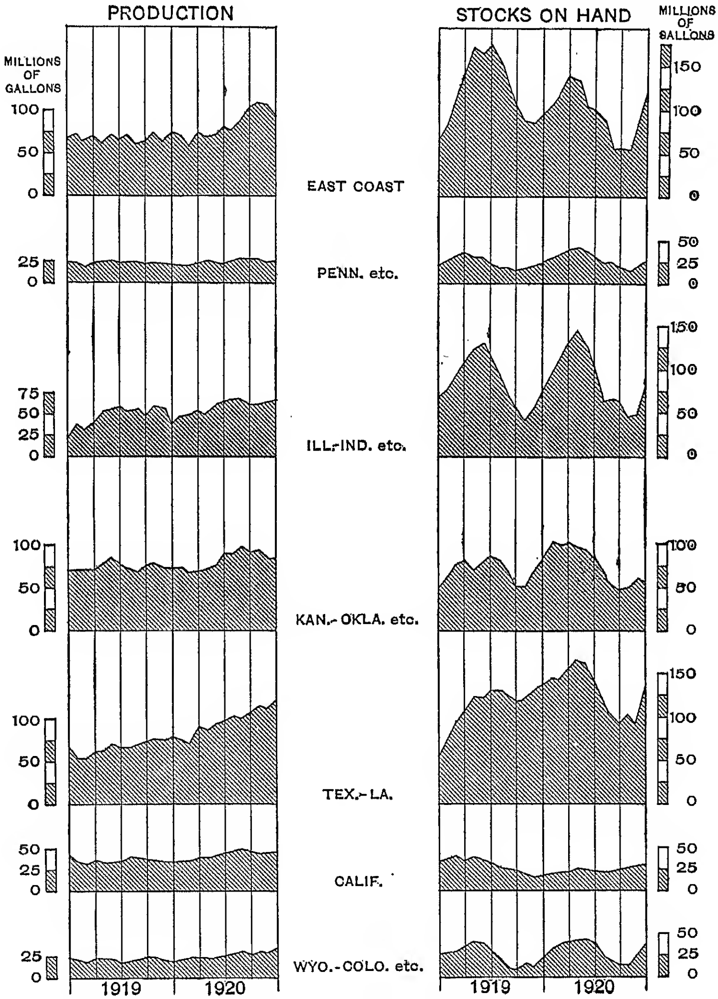


FIG. 56.—Production and stocks of gasoline in the various refinery districts of the United States by months, 1919–1920.

once dominant for cleaning, solvent purposes, and in chemical manufacture, having been relegated to an entirely subordinate position.

Measurement of the components of the gasoline demand may be made by multiplying the average number of cars, trucks, and tractors in use each year by factors representing their respective average

TABLE 50.—PRODUCTION AND STOCKS OF GASOLINE IN THE UNITED STATES BY MONTHS, 1919–1920, CLASSIFIED BY REFINERY DISTRICTS

Data from U. S. Bureau of Mines

(In millions of gallons)

	East Coast		Penn., etc.		Ind., Ill., etc.		Okla., Kan., etc.		Tex., La.		Wyo., Colo., etc.		California		Country	
	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks
1919. January	69.9	81.3	21.7	26.2	38.2	78.8	68.6	61.8	52.0	70.8	18.8	28.7	34.4	35.6	304	383
February	63.0	102	18.4	29.4	34.9	95.5	69.9	74.7	50.9	90.3	16.8	29.2	29.7	37.2	284	458
March	66.2	138	23.1	31.5	36.0	120	69.1	80.7	62.0	105	21.6	36.3	33.3	34.8	311	546
April	57.3	166	23.9	29.6	47.1	125	74.3	72.8	62.0	121	22.2	39.4	33.1	38.7	320	594
May	67.2	166	25.1	28.8	52.7	129	83.5	78.7	69.9	122	21.3	37.6	34.7	32.3	354	594
June	63.1	173	21.7	23.7	59.6	114	75.4	87.8	66.1	131	17.8	32.4	34.6	31.2	338	594
July	69.4	155	23.4	19.5	52.6	87.4	73.5	81.0	65.5	130	18.7	19.4	39.3	23.1	342	515
August	55.6	124	24.3	19.5	54.7	67.5	67.9	67.7	67.2	124	18.3	8.45	38.8	23.9	327	435
September	60.3	100	22.6	16.5	48.3	53.7	74.5	52.2	74.7	121	22.5	7.88	36.8	20.2	340	371
October	72.1	89.6	23.3	16.4	55.7	45.8	76.3	49.4	76.1	121	24.8	14.7	35.2	17.1	363	354
November	62.1	84.2	22.4	19.5	54.3	55.2	73.9	64.5	74.8	131	18.0	8.86	33.3	14.7	339	378
December	73.5	94.5	20.1	22.8	37.4	76.4	73.9	83.9	79.2	136	16.9	18.0	34.7	15.5	336	447
Year	780	.....	270	.....	571	.....	881	.....	800	.....	238	.....	418	.....	3958	.....
1920. January	68.2	104	20.7	26.8	47.1	96.9	73.3	103	75.9	143	18.5	27.3	33.0	15.6	337	516
February	57.9	119	20.0	33.0	49.7	119	69.9	98.2	68.8	141	21.9	35.4	34.4	18.2	323	563
March	71.1	139	23.4	38.6	52.9	136	71.0	102	87.3	152	23.1	40.4	38.5	19.6	367	626
April	67.0	132	24.4	40.2	47.9	143	69.9	95.8	86.0	165	22.1	42.5	38.3	24.6	356	644
May	68.0	101	23.9	35.8	60.9	127	74.1	89.4	91.4	160	23.9	43.3	38.9	21.1	381	578
June	78.9	96.0	24.0	27.7	61.4	105	89.0	82.2	95.1	136	24.5	35.4	42.3	22.3	415	504
July	74.4	86.9	24.3	23.3	65.0	82.6	87.7	69.5	101	110	25.1	24.0	45.5	17.4	423	413
August	82.0	54.1	26.7	23.7	65.9	63.8	95.6	49.2	98.5	96.2	28.8	17.5	46.7	18.7	444	323
September	99.8	55.8	24.5	17.8	62.8	48.5	90.7	46.6	103	89.8	26.7	11.1	46.0	18.6	454	288
October	104	53.2	26.3	16.7	61.7	45.2	90.4	48.3	113	101	27.9	13.9	43.1	22.7	466	301
November	104	80.2	24.7	19.3	62.2	52.3	83.4	58.1	106	93.4	27.1	26.0	44.7	25.6	453	355
December	96.1	121	25.2	25.7	65.0	74.0	83.6	56.9	118	120	31.5	37.1	45.1	28.0	464	462
Year	971	.....	288	.....	703	.....	979	.....	1144	.....	301	.....	496	.....	4883	.....

annual consumption of gasoline; and subtracting the total, together with the quantity exported, from the figures representing the country's total production which leaves a small quantity covering miscellaneous uses. The results obtained are approximations merely, because the basic data are imperfect, but the broad features of the demand may be drawn with sufficient closeness to indicate its trend and composition.

Fig. 57 analyzes the trend of the gasoline demand for the period 1910–1920 and is based on registration figures for cars and trucks, the best available data for tractors, and the following consumption factors (see Table 51) modified somewhat for 1920.

TABLE 51.—ANNUAL CONSUMPTION FACTORS FOR CARS, TRUCKS AND TRACTORS

	Passenger Cars	Light Trucks	Heavy Trucks	Average Trucks	Tractors
Av. annual consumption	300 gals.	1000 gals.	2000 gals.	1500 gals.	2000 gals.

These factors are based upon an investigation conducted by the War Industries Board in 1918,[1] modified by additional calculations and experience. The factors cannot be accepted as exact, and indeed they change from year to year. Most factors generally used represent a combined figure for cars and trucks. In both 1919 and 1920 the consumption factor for cars and trucks combined was 400 gallons (domestic consumption minus 20 per cent for tractors and miscellaneous uses, divided by average number of automotive units in use). On this basis for 1920, assuming 7,450,000 cars and 800,000 trucks as the average number in use during the year, the average consumption would be, in gallons per year:

Passenger Cars	Trucks	Combination
335 gals.	1000 gals.	400 gals.
282 gals.	1500 gals.	400 gals.

Without going into further detail, it may be stated that the true consumption factors of cars and trucks lie somewhere between the limits of 335 and 282 for cars, and 1000 and 1500 for trucks. Since, however, there is a tendency (since 1918) for the annual mileage of passenger cars to become greater, while the number of light trucks

[1] M. J. Gillen, Regulation of Uses of Motor Cars, Gasoline, Rubber Tires, and Rubber, War Industries Board, Nov. 4, 1918 (manuscript).

is increasing relative to heavy trucks, the factors of 335 gallons per year for cars and 1000 gallons for trucks are advanced as satisfactory for application to the years immediately ahead. In Figs. 57, 58, and

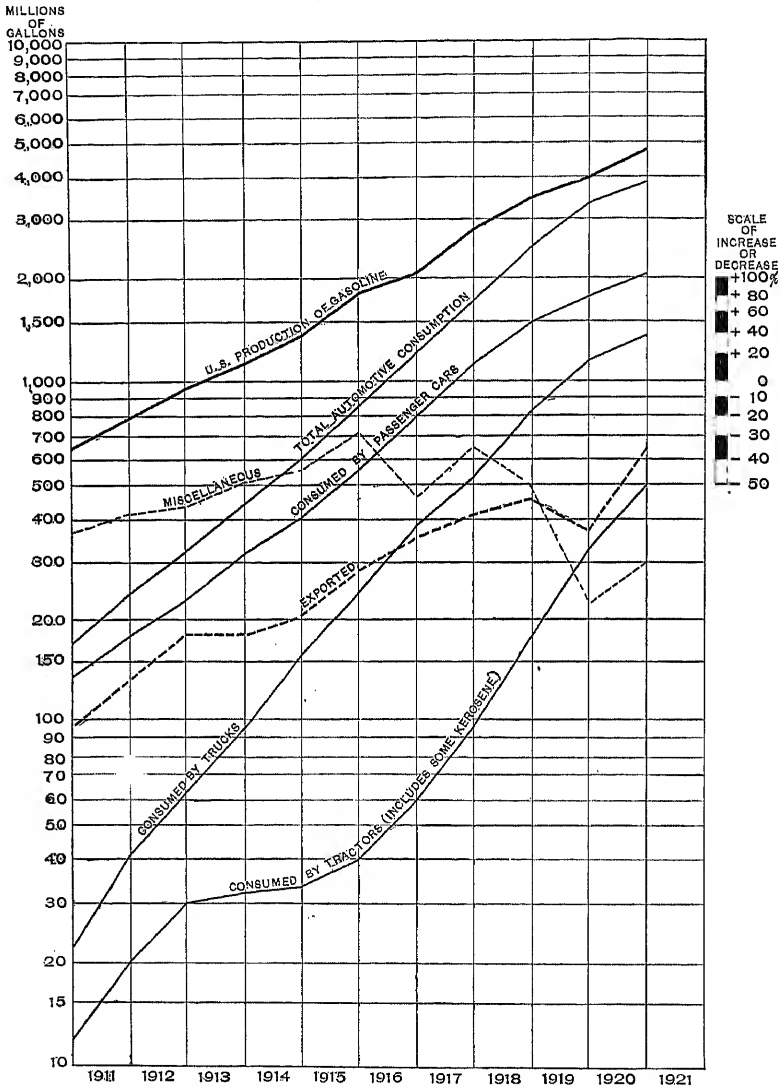


FIG. 57.—Trend of supply and demand for gasoline in the United States, 1910–1920.

59 these factors are employed for 1920, while the factors given in Table 51 are used in calculating the preceding years, thus allowing for the shifting currents in the situation.

Fig. 58 gives the data of Fig. 57 plotted so as to show the growing importance of trucks and tractors as consumers of motor-fuel. The demand chart may be seen to be made up of two fairly constant components, exports and miscellaneous, and three widening wedges, cars, trucks, and tractors. The wedges representing truck and tractor consumption, it should be observed, are in a relatively youthful stage as compared with the wedge representing the consumption of pas-

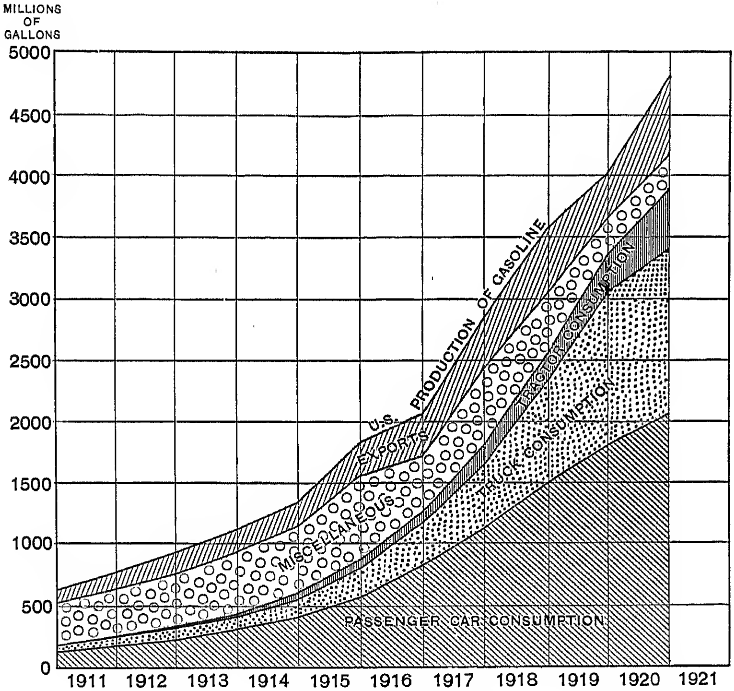


Fig. 58.—Analysis of the growth in the demand for gasoline in the United States, 1910–1920.

senger cars. The same range of data, recalculated to a percentage basis, is presented in Fig. 59 as a matter of further comparison.

Distribution of the Gasoline Demand.—The geographical distribution of the requirements for gasoline may be calculated with approximate accuracy from automotive registrations, and the results may be used effectively by marketing companies as a guide to sales development. Since the number of cars and trucks in each town and county in the country is known, the calculation of the demand is easily made by means of the consumption factors just given, modified to meet local conditions.

Consumption factors for fourteen states of various types and diverse locations are given in Table 52, which at the same time illustrates the method of calculation.

TABLE 52.—THE CONSUMPTION OF GASOLINE IN 1920 IN SELECTED STATES, TOGETHER WITH THE AVERAGE ANNUAL CONSUMPTION PER CAR

States	Gasoline Consumed,* Millions of Gallons	Average number Cars and Trucks in Use During 1920,† Thousands of Cars and Trucks	Average consumption per Unit (Cars and Trucks),‡ Gallons
Alabama	48.0	66.8	575
Arkansas	23.9	54.3	352
Colorado	51.4	117	352
Florida	53.7	64.7	665
Kansas	117	247	379
Mississippi	156	54.3	230
Nebraska	82.4	208	317
North Carolina	74.0	125	473
Ohio	273	563	388
Oklahoma	63.0	175	288
Oregon	47.6	93.6	407
South Carolina	41.2	81.5	404
South Dakota	41.0	113	290
Tennessee	57.8	91.2	507
Average	....	....	402

* Data from American Petroleum Institute.

† Data from Automotive Industries; calculated by averaging registrations of first and last of year.

‡ Calculated by discounting the annual consumption by 20 per cent to allow for tractor and miscellaneous consumption, and dividing the resultant by the average number of automotive units in use.

Wide variations in the consumption factors given are immediately noticeable, and there are certain discrepancies difficult of explanation. For general purposes, the broad averages are more useful than the detailed figures; and the latter should be used with due regard to the generalized data upon which they are based.

Seasonal Variation in Demand.—The increased consumption of gasoline in the summer months, because of the greater use of automobiles, creates a peak-load problem for the producer and marketer of gasoline. The gasoline requirements of the country are twice

as great in summer as in winter, reaching their maximum in August and their minimum in January. The summer consumption is greater than the production, and the requirements are met by heavy drafts upon the gasoline stocks that accumulate during the winter and spring months. The relation between the seasonal variation in demand and the course of stocks is marked, as shown in Fig. 60, which is based on statistical data recalculated to a common base in January. The curve showing normal consumption is a smoothed average and represents the course that demand may be expected to follow in any given year. The corresponding index numbers, together with the percentage of the year's total that each successive month may be expected to require, are presented in Table 53.

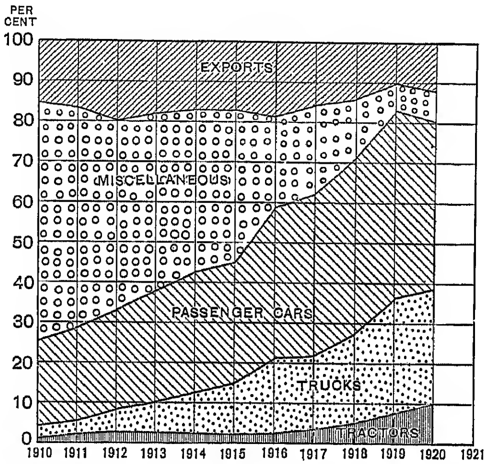


Fig. 59.—Percentage analysis of the demand for gasoline, 1910–1920.

As the demand for gasoline increases and the volume of gasoline required to meet the summer demand grows larger, the handling of the peak-load becomes more and more difficult. Any stringency, or shortage, in gasoline that may come is bound to develop in the summer season. A gasoline shortage in August, therefore, does not mean an inadequate production of gasoline so much as an unequalized load coming to a focus in that month.

During the period 1918–1920 the stocks of gasoline, while trending upward in an absolute sense, have not been keeping pace with the rise in production or demand. Fig. 61 shows the downward plunge taken by the stock curve in 1920 and reflects the growing difficulty ahead in meeting the climax in demand. A converging trend between stocks and consumption, as shown in Fig. 61, cannot continue without ultimately leading to a failure of supply at the peak season.

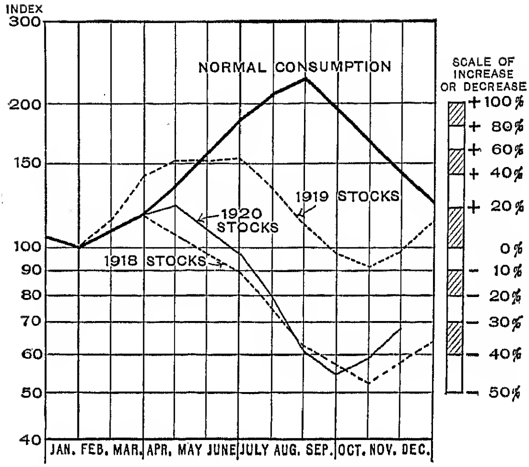


FIG. 60.—The seasonal variation in the demand for gasoline compared with seasonal changes in the volume of gasoline in storage.

TABLE 53.—THE SEASONAL DEMAND FOR GASOLINE IN THE UNITED STATES

Months	Index Numbers	Percentage of Year's Total
January	100	5.4
February	108	5.8
March	120	6.4
April	135	7.2
May	160	8.5
June	185	9.9
July	210	11.2
August	220	11.8
September	195	10.4
October	165	8.8
November	147	7.9
December	125	6.7
		100.0

The significance of the declining ratio of stocks to requirements is further shown in the following tabulation:

TABLE 54.—THE SIGNIFICANCE OF THE STOCKS OF GASOLINE IN THE UNITED STATES IN SEPTEMBER, 1917–1920

	Sept., 1917	Sept., 1918	Sept., 1919	Sept., 1920
Ratio of stocks to domestic consumption...	116%	85%	100%	65%
No. of days' supply represented by stocks..	35	26	30	19½

The peak-load problem, long recognized and aggressively handled in the electrical industry, is growing in seriousness in connection

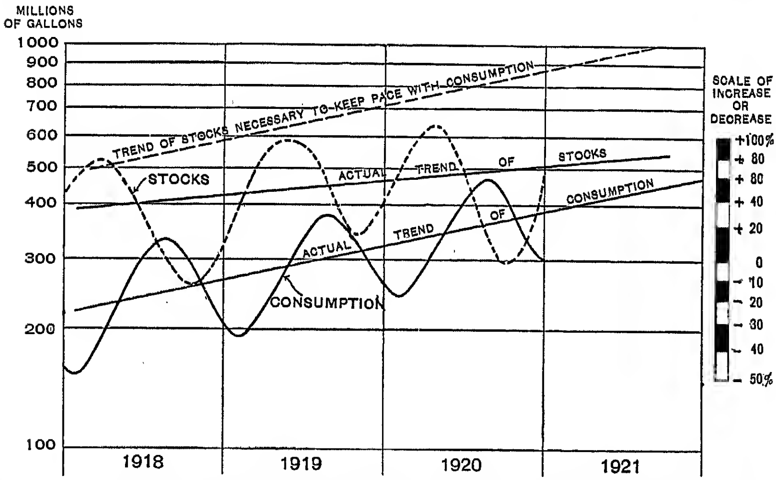


FIG. 61.—The converging trend of gasoline stocks and gasoline consumption, pointing to the growing difficulty of supplying the peak requirements of summer.

with the supply of gasoline. Gasoline storage is not developing as rapidly as the peak of demand is rising, and unless this relationship is reversed the supply will thin out to a stringency in an early summer ahead, even granted an adequacy of crude to maintain production. Should a shortage of crude at the same time supervene this stringency will break into a shortage, calling widespread attention to the situation.

CHAPTER X

KEROSENE

Kerosene, that fraction of crude petroleum intermediate in character between gasoline and distillate fuel oil (gas oil), affords an interesting example of a product whose economic status has been profoundly affected by modern technical changes in fields impinging upon its own. Once the mainstay of the oil-refining industry, kerosene has been relegated to a relatively subordinate position, and the output of this product in the United States has recently reached its maturity.

When the petroleum industry developed in the United States following the discovery well on the Drake farm in Pennsylvania in 1859, a product distilled from coal and known as "coal oil" was in widespread use as an illuminant. It was soon found that crude petroleum, by a process of distillation and chemical treatment, could be made to yield an illuminating oil suitable for use in lamps. For many years, the efforts of the oil-refining industry were mainly devoted to the development of kerosene and the extension of markets for this product with sufficient speed to give vent to the mounting volume of crude petroleum. Domestic markets alone proved inadequate, so the foreign field was vigorously attacked and American kerosene was sent to the four corners of the globe, to lengthen the days of the peoples of the entire world. "It would be difficult indeed to estimate the value to the world at large of this cheap and convenient source of light, which has been aptly termed 'one of the greatest of all modern agents of civilization.'"

The supply of raw material for the manufacture of kerosene continued to grow and toward the close of the Nineteenth Century the commercial development of gas and electricity began to narrow the domestic market, throwing still greater emphasis upon the importance of expanding the foreign outlet. In the meantime the volatile components of the crude petroleum had to be separated from kerosene and thus a supply of gasoline was being developed, without a corresponding demand, and gasoline for a time became a drug on the market. Into this setting came the commercial development of the internal combustion engine and the phenomenal rise of automotive transportation, with results familiar to everyone. Kerosene was

soon forced to the background, and gasoline has supplanted kerosene as the leading representative of the joint-products of petroleum.

The Waning Status of Kerosene.—In 1899 the output of kerosene was 58 per cent of the crude petroleum run to stills; while in 1914 this proportion had dropped to 24 per cent; and in 1920 to 12.7 per cent. The declining ratio of kerosene output to crude run is shown for the years for which figures are available in the following table:

TABLE 55.—PERCENTAGE OF KEROSENE PRODUCED FROM THE CRUDE PETROLEUM RUN TO STILLS IN THE UNITED STATES, 1899–1920

Data from U. S. Census and U. S. Bureau of Mines

Year	Crude Run to Stills, Billions of Gallons	Kerosene Produced, Millions of Gallons	Kerosene Produced, Percentage of Crude Run
1899	2.18	1259	58
1904	2.81	1357	48
1909	5.07	1675	33
1914	8.04	1935	24
1916	10.4	1455	14.0
1917	13.2	1727	13.1
1918	13.7	1825	13.3
1919	15.2	2342	15.4
1920	18.2	2320	12.7

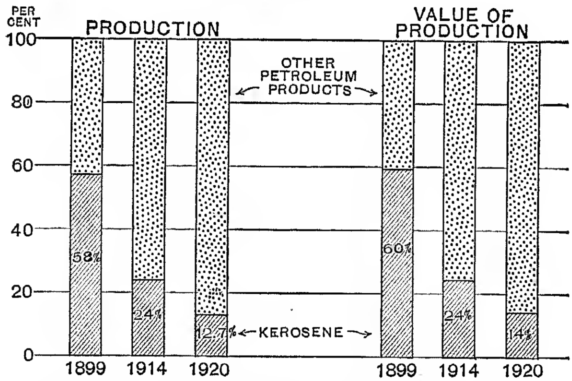


FIG. 62.—The relative importance of kerosene compared with other petroleum products in the United States in 1899, 1914, and 1920.

The value of the kerosene produced in the United States, in percentages of the value of the total products of the still, was 60 per cent in 1899, 24 per cent in 1914, and approximately 14 per cent in 1920. The trend of the relative decline in output and in value of kerosene is shown graphically in Fig. 62.

Sources of Supply.—The quantity of kerosene produced in the various refinery districts of the United States in 1918, 1919, and 1920, together with the percentage yields of the total oils run to stills, is shown in Table 56. (See also Fig. 63.)

TABLE 56.—PRODUCTION OF KEROSENE IN THE UNITED STATES BY REFINERY DISTRICTS, 1918–1920

Refinery District	1918		1919		1920	
	Production, Millions of Gallons	Per Cent of Total Oils Run to Stills	Production, Millions of Gallons	Per Cent of Total Oils Run to Stills	Production, Millions of Gallons	Per Cent of Total Oils Run to Stills
East Coast	486	16.2	703	20.6	497	12.9
Pennsylvania, etc.	137	15.7	191	20.0	173	17.6
Illinois, Indiana, etc.	187	14.8	217	13.1	217	10.9
Kans., Okla., etc.	415	14.1	393	13.7	394	13.0
Texas, Louisiana	435	11.9	569	14.3	714	13.7
Wyoming, Colorado	62.7	9.0	65.7	7.8	117	11.7
California	103	3.1	204	6.0	207	6.0
Total	1825	11.6	2342	13.6	2320	11.9

It will be observed that there is a marked variation from year to year in the percentage yields of kerosene. This flexibility reflects the readiness with which the limits of kerosene are shifted under varying economic conditions, the light ends of kerosene going into gasoline or not as occasion demands, and the heavy ends being likewise interchangeable with gas oil. In general, the year 1919 shows much higher kerosene yields than do 1918 and 1920, a circumstance to be correlated with the fairly abundant supply of gasoline relative to demand in 1919 and the contrary tightness of supply in 1918 and 1920.

Fig. 63 emphasizes the importance of the contribution to the country's supply of kerosene made by the south-central states.

Relation to Gasoline.—The tendency over the past few years for the light ends of kerosene to be incorporated into the gasoline supply has been fully discussed in Chapter 9. In addition to this progressive transfer from year to year, as the demand for gasoline mounts, there is a seasonal relationship within the year, the kerosene output relative to the quantity of oils run to stills being in general less in summer than in winter. The calculations supporting this conclusion are presented in Table 57.

The degree of correlation between season and percentage yield of kerosene may be effectively shown by recalculating Table 57, taking the yields for the third quarter of the year as a base of 100. The results of such a calculation are presented in Table 58.

It is apparent that the kerosene yields bear a very consistent and definite relation to the season, the only exception being offered by the Wyoming-Colorado refinery district. The relationship is definitely traceable to the demand for gasoline, which as shown in Chapter IX, falls upon the four

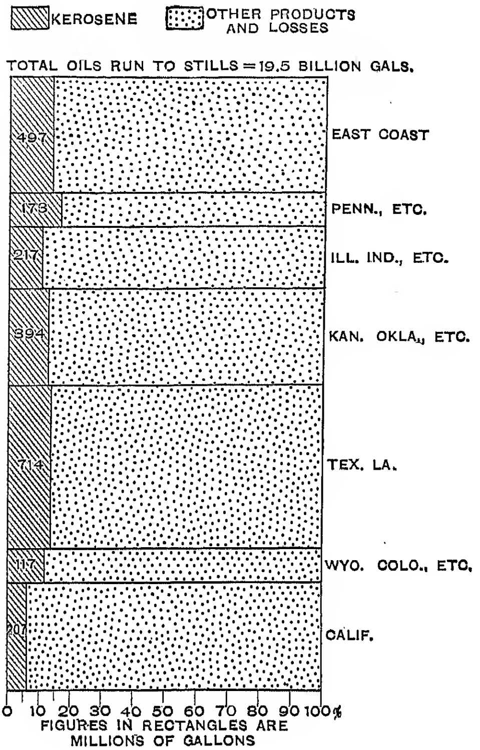


FIG. 63.—The production of kerosene compared with the production of other petroleum products in various parts of the United States in 1920.

TABLE 57.—PERCENTAGE YIELDS OF KEROSENE RELATIVE TO TOTAL OILS RUN TO STILLS IN VARIOUS PARTS OF THE UNITED STATES DURING THE FOUR QUARTERS OF 1920

Refinery Districts	Yield of Kerosene in Percentages of Total Oils Run to Stills: First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Year
East Coast......	15.7	11.4	10.0	10.2	12.9
Pennsylvania, etc.	18.9	18.0	15.8	17.9	17.6
Ill., Ind., etc.....	11.8	10.9	9.6	11.4	10.9
Kan., Okla., etc..	14.4	12.6	10.8	13.8	13.0
Tex., La.........	15.3	13.2	12.9	13.1	13.7
Wyo., Colo., etc..	10.6	13.3	12.1	11.3	11.7
California.......	6.6	5.9	5.6	5.9	6.0
Country.........	13.6	11.6	10.6	11.5	11.9

quarters of the year, in percentages of the full year's requirement, as follows:

1st Q.	2d Q.	3d Q.	4th Q.
17.6 per cent	25.6 per cent	33.4 per cent	23.4 per cent

Plotting the average gasoline demand against the average kerosene yields, we get two complementary curves, as shown in Fig. 64, which reflect the seasonal response made by the kerosene supply to the gasoline demand. In other words, in summer more of the light kerosene ends are introduced into the gasoline supply than in winter. This tendency is in keeping with the seasonal variation in the end-point of gasoline, as interpreted in Fig. 49, page 112.

TABLE 58.—YIELDS OF KEROSENE BY QUARTERS OF 1920 IN PERCENTAGES OF THE YIELD IN THE THIRD QUARTER OF THE YEAR

Refinery Districts	First Quarter	Second Quarter	Third Quarter	Fourth Quarter
East Coast	157	114	100	102
Pennsylvania, etc.	120	114	100	113
Illinois, Indiana, etc.	123	114	100	119
Kansas, Oklahoma, etc.	133	127	100	128
Texas, Louisiana	119	102	100	101
Wyoming, Colorado, etc.	88	110	100	94
California	118	105	100	105
Country	128	110	100	109

Current Trend of Supply and Demand.—The trend of the major factors entering into the interplay between supply and demand is shown by months for the period 1917–1921 in Fig. 65, the supporting data appearing in Table 59. The outstanding features of the chart are: The horizontal trend of domestic consumption; the high ratio of exports to domestic consumption; the upward tendency in stocks on hand in 1919 and 1920; and the steady price advance in 1919–1920 in particular, showing only a slight recession in the fourth quarter of 1920. Fig. 65 is presented as a type of chart particularly suitable for use in following the current situation from month to month, and the flow of the lines across the page giving the basis for drawing conclusions as to developments lying ahead.

Relation of Production to Stocks.—The size and trend of production by months compared with the stocks of kerosene on hand in the various refinery districts in the United States for 1919 and 1920

are shown graphically in Fig. 66. The chart brings together the refinery statistics for kerosene in a form suitable for drawing deductions as to the variations in supply and demand in various parts of the country. The type of chart is presented as a practical method of interpreting a complex range of statistics difficult of analysis in tabular form. The data on which the chart is based are given in Table 60.

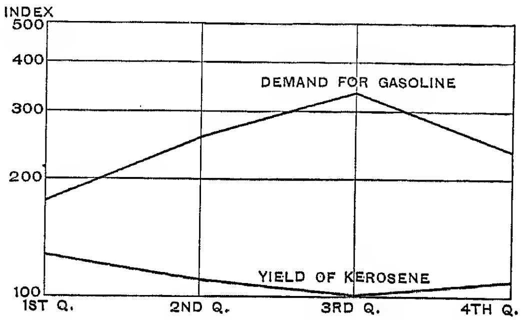


Fig. 64.—Seasonal correlation between the demand for gasoline and the yield of kerosene.

The outstanding feature of Fig. 66 is the large accumulation of stocks in the East Coast and Texas-Louisiana districts. A contrast is offered for the year 1920 between the declining production of the East Coast district and the steadily advancing output of the Texas-Louisiana region.

Analysis of Demand.—The demand for kerosene is mainly for purposes of illumination and heating, although of recent years a growing quantity has come under requisition for power purposes in tractors, motor-boats, and stationary engines. The exact percentage consumed for power purposes is difficult to ascertain, because reliable statistics on the number of power units in use are not available and many appliances are designed to use either gasoline or kerosene. A rough interpretation of the trend of demand, with no pretense to exactitude, is presented in Fig. 67.

It will be observed that export requirements have always bulked large, although foreign shipments suffered serious curtailment during the war, particularly in 1917 and 1918 when the far eastern markets were difficult of access because of the shortage in shipping. The increase in domestic demand has been slight compared with the rapid rate at which gasoline requirements have grown; and much, if not all, of the recent increase has been due to the employment of kerosene for power purposes.

TABLE 59.—SUMMARY OF THE KEROSENE SITUATION

Period		Production, Millions of Gallons	Stocks,* Millions of Gallons	Exports, Millions of Gallons	Domestic Consumption, Millions of Gallons	Average Domestic Price (Tank-wagon) Cents per Gallon	Average Export Price, Cents per Gallon
By years:	1914	1935	....	1010	....	7.6	6.3
	1915	....	....	837	....	7.1	6.0
	1916	1455	....	855	....	7.9	6.5
	1917	1727	498	658	....	8.5	7.4
	1918	1825	380	491	1452	10.2	10.3
	1919	2342	339	979	1404	12.7	12.2
	1920	2320	393	862	1404	17.1	15.4
By months:							
1919.	January	159	332	68	138	10.9	10.0
	February	164	303	67	126	10.9	11.2
	March	170	295	54	124	11.1	12.0
	April	183	276	93	108	11.4	10.8
	May	190	245	80	142	11.8	12.3
	June	179	253	124	47.1	12.4	11.9
	July	206	280	76	103	13.3	12.0
	August	220	296	84	120	13.9	12.6
	September	199	312	73	110	14.0	13.2
	October	227	329	94	115	14.3	12.6
	November	215	347	70	132	14.3	14.9
	December	229	339	93	144	14.6	12.8
By months:							
1920.	January	196	328	81	127	15.6	13.4
	February	195	330	76	116	15.8	13.7
	March	191	335	80	107	16.3	13.9
	April	184	376	68	74	16.6	14.7
	May	181	419	57	81	16.6	17.2
	June	174	421	62	110	17.0	17.1
	July	172	411	59	124	17.1	16.5
	August	189	379	75	146	18.0	16.9
	September	199	379	63	135	18.2	14.8
	October	214	384	70	140	17.8	15.1
	November	215	399	81	119	17.8	16.0
	December	211	393	90	127	17.8	15.7
By months:							
1921.	January	205	419	79	100	17.5	18.4
	February	163	430	68	84	14.9	16.2
	March	169	446	64	89	14.6	15.7
	April	156	459	59	84	14.0	15.1
	May	145	452	52	100	12.6	11.4
	June	142	435	64	95	11.5	12.8

There are many specialized uses to which kerosene is put, on which consumption statistics are not available. One of the most interesting of these uses is in the tail-lights on trains, where a special type of long burning kerosene is still employed even when the train

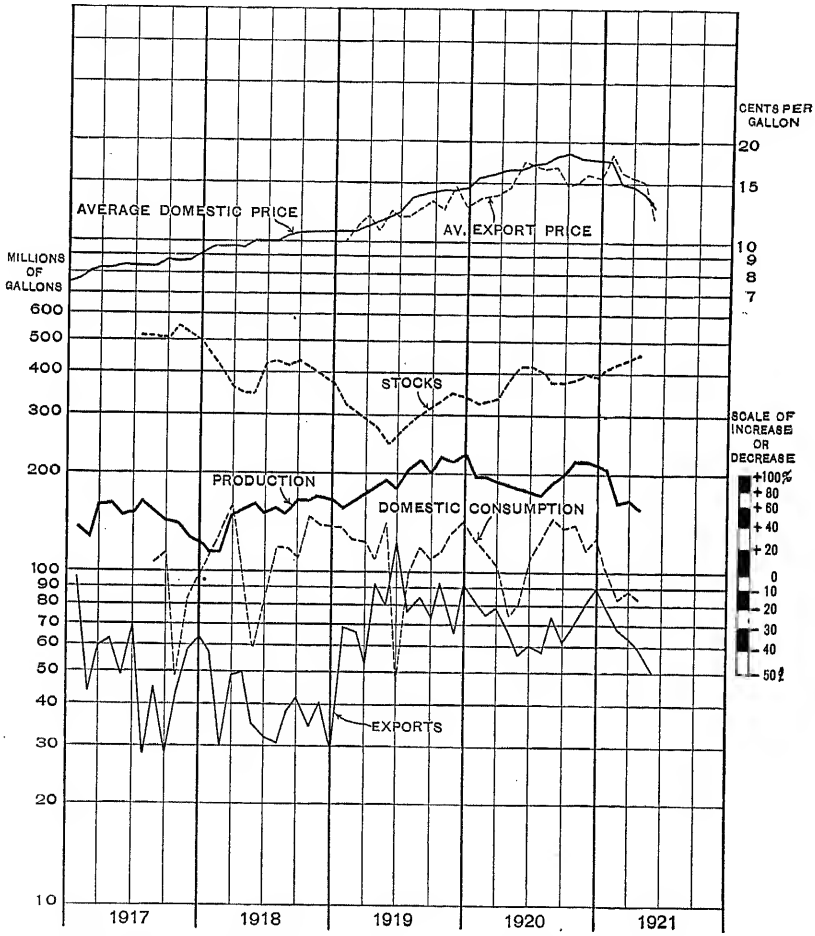


FIG. 65.—Trend of the kerosene situation in the United States by months, 1917–1921.

is otherwise illuminated with gas or electricity. The persistence of kerosene in this connection illustrates the fundamental importance of *form value,* since the cardinal requirement is dependability under any emergency, to which the form of kerosene is better adapted than either gas or electricity.

TABLE 60.—PRODUCTION AND STOCKS OF KEROSENE IN THE UNITED STATES BY MONTHS, 1919–1920, CLASSIFIED BY REFINERY DISTRICTS

Data from U. S. Bureau of Mines

(In millions of gallons)

Period		East Coast		Penn., etc.		Ill., Ind., etc.		Kan., Okla., etc.		Tex., La.		Wyo., Colo., etc.		California		Country	
		Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks
1919.	January	45.1	53.0	13.2	16.7	15.8	18.5	30.1	17.8	37.1	201	3.99	11.9	13.2	13.1	159	332
	February	43.9	54.2	15.0	20.4	15.2	20.3	30.0	14.3	42.4	170	3.38	11.6	14.3	12.4	164	303
	March	48.9	68.7	16.7	22.9	15.8	17.0	33.2	13.9	38.5	151	5.19	11.3	12.0	9.95	170	295
	April	54.1	60.1	15.7	23.5	18.2	16.0	31.8	11.8	43.2	144	4.01	8.31	16.4	13.1	183	276
	May	62.1	63.2	17.3	23.9	18.5	13.7	33.4	10.6	42.2	116	3.14	4.03	13.7	13.2	190	245
	June	61.6	72.5	15.6	21.9	8.31	18.6	29.0	11.3	44.9	113	4.67	2.74	15.0	12.6	179	253
	July	63.0	93.9	17.2	19.5	14.8	21.0	32.6	13.1	48.7	110	6.82	7.19	22.5	15.1	206	280
	August	71.1	99.4	17.3	19.5	15.2	24.3	33.2	14.7	52.8	113	5.71	4.46	24.1	20.8	220	296
	September	60.5	115	16.5	17.6	14.2	25.3	34.6	15.9	50.1	111	7.63	5.61	15.6	21.6	199	312
	October	67.9	127	18.3	18.2	16.6	28.9	38.2	16.3	58.8	110	7.93	10.5	19.3	18.4	227	329
	November	70.7	136	13.9	16.6	14.6	37.5	35.7	19.4	54.9	109	6.68	9.83	18.3	18.2	215	347
	December	54.2	103	13.9	16.4	49.5	40.7	31.0	22.1	55.2	133	6.54	11.1	19.1	12.9	229	339
Year		703	.....	191	.....	217	.....	393	.....	569	.....	65.7	.....	204	.....	2342	.....
1920.	January	47.7	79.2	14.3	13.6	17.3	49.2	33.6	25.3	61.4	130	5.21	12.4	16.5	17.8	196	328
	February	43.0	80.3	13.7	12.9	19.3	54.4	31.9	26.1	62.3	131	8.41	13.5	15.9	12.0	195	330
	March	40.9	86.7	13.7	14.1	16.4	53.7	33.7	31.1	58.1	124	8.88	15.0	19.4	9.75	191	335
	April	45.6	100	15.2	16.9	14.2	51.2	31.5	32.3	52.3	152	8.25	15.4	17.5	8.51	184	376
	May	39.2	110	15.6	23.4	17.9	54.7	30.7	41.4	52.2	162	10.6	17.0	14.6	10.9	181	419
	June	23.0	103	14.0	26.1	19.6	49.9	29.0	46.2	60.7	166	11.3	18.8	15.9	11.7	174	421
	July	35.0	113	12.8	25.2	17.2	46.3	27.9	30.7	55.0	160	7.90	20.6	16.3	15.0	172	411
	August	38.0	93.7	15.1	31.1	17.7	47.4	32.7	25.5	57.8	145	9.97	19.3	17.7	16.3	189	379
	September	37.3	105	13.5	22.0	18.0	35.7	34.5	19.1	62.8	153	14.6	22.3	18.5	22.1	199	379
	October	50.0	85.8	14.9	22.1	20.0	32.9	37.4	25.0	63.7	169	10.4	23.4	17.3	25.7	214	384
	November	49.4	79.3	15.3	21.4	19.0	33.8	35.4	29.3	68.2	186	9.26	23.2	18.3	26.6	215	399
	December	47.6	77.4	15.3	22.6	20.8	35.5	35.6	26.5	59.8	181	12.2	22.1	19.4	28.1	211	393
Year		497	.....	173	.....	217	.....	394	.....	714	.....	117	.....	207	.....	2320	.....

The Changing Character of Kerosene.—The major use of kerosene is for lighting and in the early days of its development constant

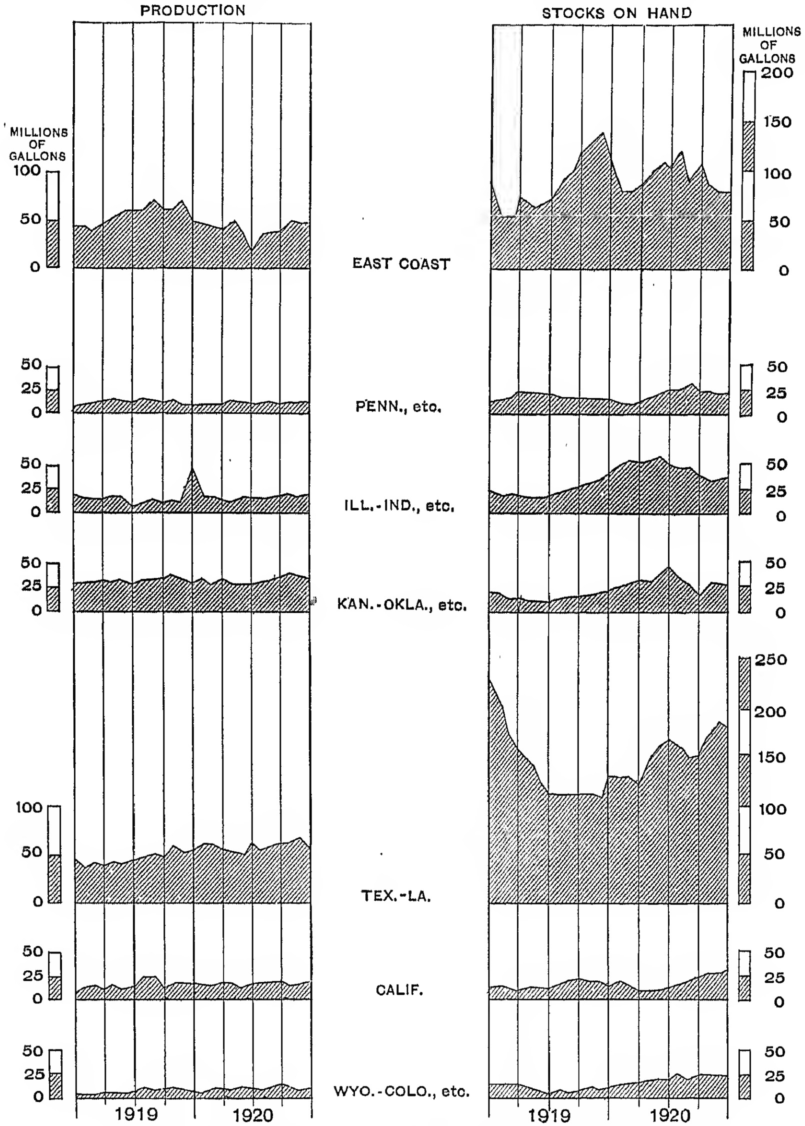


Fig. 66.—Production and stocks of kerosene in the various refinery districts of the United States, by months, 1919–1920.

effort was expended upon obtaining a product with requisite wick-climbing properties. Even in testing the commercial product to-day, no chemical examination has succeeded in replacing the practical

test in a lamp. No end of ingenious work has also been devoted to perfecting the kerosene lamp, so that to-day we have a delicately adjusted balance between the physical properties of the fuel, on the one hand, and the mechanical properties of the appliance, on the other. Of late years, however, the shift of the light kerosene ends into the gasoline supply, together with certain compensating changes at the heavy end of the series, has somewhat disturbed the balance and created new problems in the manufacture of kerosene.

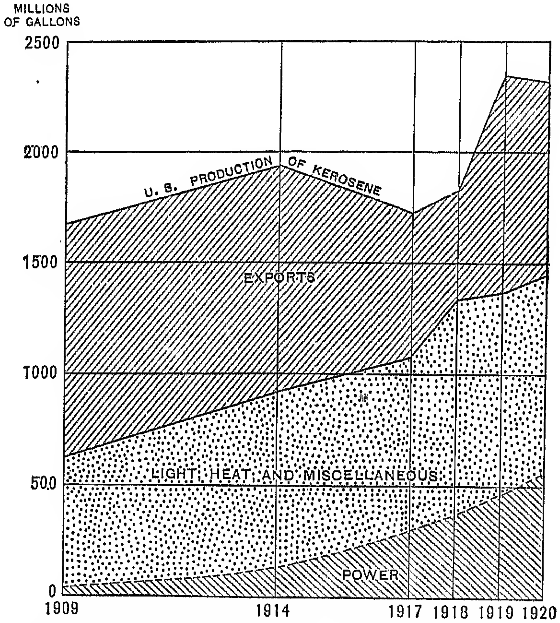


FIG. 67.—Analysis of the demand for kerosene, 1909–1920.

If the demand for gasoline dictates still deeper cuts into the crude, causing further encroachment upon the light kerosene ends, a point will soon be reached when the supply will be thrown out of adjustment with the whole range of appliances to which it is now complementary. Here again, therefore, we have a curious example of how shifting economic currents critically affect the mechanical details of technical developments.

The Future of Kerosene.—The demand for motor-fuel is so insistent that it is already encroaching upon the supply of kerosene, both directly and indirectly—directly by the development of engines designed to burn kerosene, and indirectly by the blending of light kerosene ends with the gasoline supply. Much attention has also

been devoted to cracking kerosene into gasoline, although commercial success has not yet been attained in this direction.

The future requirements for motor-fuel loom so large that it seems inevitable that kerosene should be still further encroached upon. Whether this tendency will proceed to the point of completely extinguishing the product as an illuminating agent cannot wholly be foreseen, although it would not be entirely unexpected if this product some years hence should be known as "the light that failed." Over against this contingency, however, must be placed the social importance of kerosene to the farm and rural community; and while the economic pressure of rising price will tend to divert it from this social rôle, counter forces of a politico-economic nature may set up adequate defense to save a modicum of supply from utter extinction.

CHAPTER XI

FUEL OIL

In an economic sense, fuel oil is the residue left over from the country's supply of crude petroleum after other demands are satisfied. This product comprises three varieties: Crude used as such; residuum fuel oil derived mainly from skimming and topping refineries; and distillate fuel oil, or gas oil, turned out chiefly by intermediate and complete-run refineries. The relative proportions of these three types carry considerable significance in respect to the future course of this commodity. A rough approximation of the ratio of crude oil used as such to fuel and gas oil is given in Fig. 68. The U.S.Bureau of Mines has estimated the ratio of distillate fuel oil to residuum fuel oil for the year 1918, as follows:

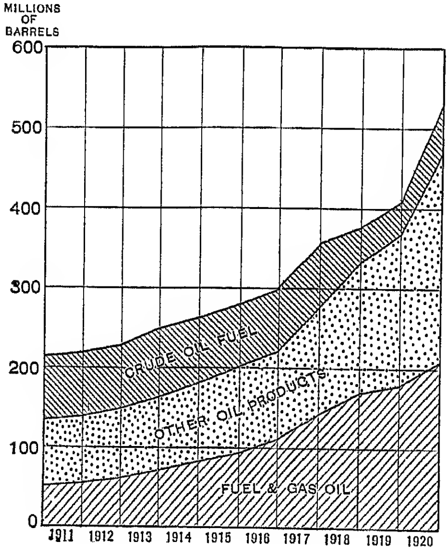


FIG. 68.—The relation between fuel oil, other oil products, and crude oil fuel in the United States, 1910–1920.

TABLE 61.—FUEL-OIL SUPPLY IN 1918 BY TYPES OF FUEL

Product	Millions of Barrels	Per Cent of Total
Distillate fuel oil, or gas oil....	19*	8
Light residuum fuel oil........	48	21
Heavy residuum fuel oil.......	164	71

* The American Gas Association estimates the 1919 output of distillate gas oil to be 30 million barrels, as likewise does the Census of Manufactures for 1919.

It will be observed from these proportions, which have not greatly changed since 1918, that residuum fuel oil overwhelmingly predominates over distillate fuel oil, with the heavy variety of residuum in striking excess of the light. Fig. 68 and the table above emphasize the residual character of fuel oil, which suggests why this product has so characteristically commanded a low price and suffered wide fluctuations in market value.

Sources of Fuel Oil.—Fig. 69 compares the output of fuel oil with the production of other oil products in various parts of the country in 1920. It will be noted that the refineries of the East Coast, of Oklahoma-Kansas, of Texas-Louisiana, and of California represent the dominant sources of this product. Leaving the California output to one side, since the Far West and exports consume the fuel-oil of that state, the oil fuel available to the rest of the United States is seen to be derived almost entirely from refineries on the East Coast and in the south-central portion of the country. The rapid development of the oil-fields of the Mid-Continent, the Gulf Coast, and Mexico is directly responsible for this grouping of production, since crude petroleum has thereby been made available in advance of the higher types of requirements and in consequence the major portion has been forced to find an outlet for the time being in the only available direction—as steam raising fuel in competition with coal. This outcome has also been accentuated by the growing prominence of heavy, asphaltic crudes in the country's supply, a type of raw material ill adapted to yielding at once high percentages

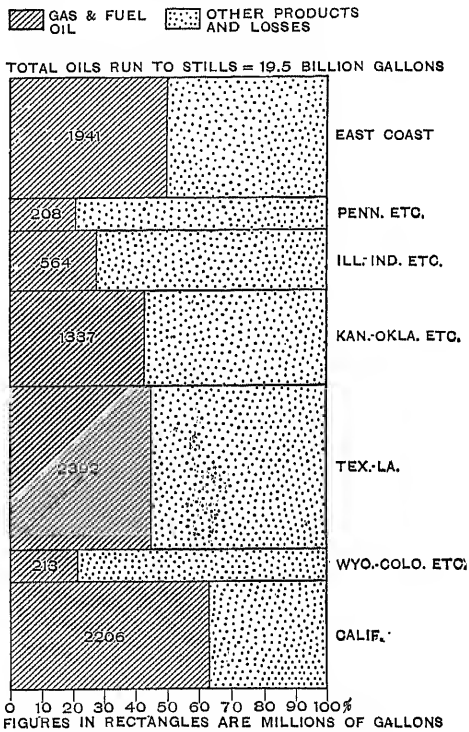


Fig. 69.—The production of gas and fuel oil compared with the production of other petroleum products in various parts of the United States in 1920.

of the more desirable oil products by means of the technology developed for treating the lighter oils. To a notable degree, fuel oil is the accompaniment of oil-field development in advance of adjustments in demands and in refining technology.

The output and percentage yield (with reference to the total volume of oil distilled) of fuel and gas oil[1] in the various refinery districts of the United States for 1918, 1919, and 1920 are shown in the following table:

TABLE 62.—PRODUCTION AND PERCENTAGE YIELD OF FUEL AND GAS OIL IN THE UNITED STATES BY REFINERY DISTRICTS, 1918–1920

Refinery District	1918		1919		1920	
	Production, Millions of Gallons	Per Cent of Total Oil Run to Stills	Production, Millions of Gallons	Per Cent of Total Oil Run to Stills	Production, Millions of Gallons	Per Cent of Total Oil Run to Stills
East Coast........	1119	37.3	1226	35.9	1941	50.3
Pennsylvania, etc...	202	23.2	169	17.8	208	21.1
Illinois, Indiana, etc.	344	27.2	408	24.8	564	28.4
Kan., Okla., etc....	1344	45.6	1259	44.0	1337	44.0
Texas, Louisiana...	1934	52.9	1912	48.1	2392	45.9
Wyoming, Colorado.	244	35.1	280	33.4	213	21.3
California.........	2138	63.6	2300	67.7	2206	63.8
Total.........	7321	46.3	7627	44.3	8861	45.5

It will be observed that while the percentages of oils distilled that were turned into fuel and gas oil have remained fairly constant over the three-year period for the country as a whole, marked changes have taken place in several of the refinery districts. For example the East Coast refinery district shows a jump from a 35.9 per cent yield in 1919 to a 50.3 per cent yield in 1920, an advance attributable to the great volume of Mexican crude subjected to topping in the latter year; while the Texas-Louisiana and Wyoming-Colorado districts show a steady decline from 1918, a change arising from the growth of complete-run refineries on the Gulf Coast and of cracking installations for converting fuel oil into gasoline in Wyoming. With a curtailed supply of crude and a mounting demand for light distillates, the average percentage yield for the country as a whole will ultimately tend significantly downward.

[1] In the official statistics, gas oil and fuel oil are not separately reported.

Relation to Refinery Practice.—There are four connected and overlapping stages in the evolution of refinery practice in the United States, through which the older producing fields of the country have entirely passed and through one or the other stages of which the newer fields are now progressing. Thus the crude petroleum produced may be (*a*) used as such, with a modicum of preparation; (*b*) subjected to topping or skimming processes, in which a part of the gasoline and kerosene is extracted, leaving the dominant portion of the crude as a residuum to be used for fuel; (*c*) treated to more complete refining, in which a larger number of commodity values, including lubricants, are extracted; or (*d*) submitted to cracking refining, in which not only an approach to a full extraction of commodity values is made, but a portion of the less valuable components is subjected to rigorous treatment for conversion into more valuable products.

Where the crude is used in the raw state, practically the whole output is fuel oil. With topping or skimming refining in its various stages, from 50 to over 90 per cent of the raw material is turned out as fuel oil. With transition to complete refining, the proportion of fuel oil becomes decreasingly less and partly of a superior quality (distillate gas oil); and when cracking refining is introduced, fuel oil (or rather its preferred variety, gas oil) becomes in turn the raw material for further refining, and the yield of fuel oil is cut down in still further degree.

Topping and skimming plants go along with flush conditions in oil-field development. They spring up quickly wherever the supply of crude petroleum is abundant and cheap; they require a relatively small outlay of capital and for a period are profitable, in many instances exceedingly so. With high cost crude, however, they become uneconomic, and either cease to operate or change to plants making a fuller extraction of values. Up to the present the topping and skimming capacity of the country, while showing fluctuations in conformance to conditions of supply and demand in the oil market, has been increasing, owing to the upgrowth of new plants in excess of the plants going out of existence or changing over to more complete refineries. The development of topping plants has also been stimulated by the mounting imports of crude oil from Mexico, although many skimming plants were forced out of existence in the Mid-Continent and Gulf regions under the conditions of reduced demand that came into play in late 1920 and early 1921. As oil-production conditions mature, however, the topping and skimming types will tend to give way to complete refineries and the relative yields of fuel oil will decline to proportions characteristic of such refinery districts as Pennsylvania and Illinois-Indiana. (See Fig. 69.)

Development of Cracking Refining.—In response to the expanding demand for motor-fuel the upgrowth of cracking refining has been conspicuous since 1915. In 1920 roughly 15 million barrels of gasoline were contributed by cracking, over the quantity producible without its aid. This output, in turn, represented a consumption of from 30 to 40 million barrels of distillate fuel oil, or gas oil. The inevitable result of such a large diversion of gas oil was seen in the 1920 shortage of this product and the concurrent agitation of the gas manufacturers under this head.

The evident inability of cracking growth to keep pace with the increasing demand for motor oil has been reflected in a change in end-point of gasoline, which in turn has increased the consumption of motor oil as a result of crank-case dilution. This effect has further stimulated the upgrowth of complete-run refining at the expense of skimming processes. Thus another cycle of events has been tending in the direction of curtailment in fuel oil output. The various factors in the situation are complex, displaying many fluctuations and reversals; but the net changes are toward an ultimate curtailment in the percentage yield of fuel oil.

Excessive Competition in Marketing Fuel Oil.—In recent years, the output of fuel oil in the newly developed oil sections of the country has created unsettled marketing conditions for this product. Because of the bulk in which fuel oil was produced, the difficulties of maintaining adequate storage, the seasonal character of the demand, and other factors, keen competition in marketing resulted. In point of fact, competitive efforts in excess of what was advantageous or even necessary were frequently in evidence, since lack of confidence on the part of refiners with storage tanks approaching the limit of capacity often led to a feeling of overproduction, which resulted in drastic price cutting and other measures destructive of profitable disposal. Such conditions were aggravated also by a periodic overproduction of crude petroleum, as in the Cushing field in 1915, in the North Texas fields in 1919, and throughout much of the country in 1920–1921.

As the situation is shaping up ahead, with a dearth of crude petroleum and growing demands in prospect, the competitive conditions surrounding the marketing of fuel oil will be largely mitigated. A foretaste of this prospect was afforded in the winter of 1917–1918 under the stress of war conditions. The reaction of 1919, arising from an overstimulation of productive effort in the face of an immediate stoppage in war requirements, was merely a passing incident. In late 1919 the influences outlined above come forward with due effect accentuated by the coal strike and by restrictions in transpor-

tation facility. Again in 1920–1921 conditions swung to the opposite extreme, when a highly stimulated crude production both in this country and Mexico found an inappropriate economic setting in a time of industrial depression. But ultimately supply will lag permanently behind demand and then the whole country may be expected to experience a growing scarcity of this product.

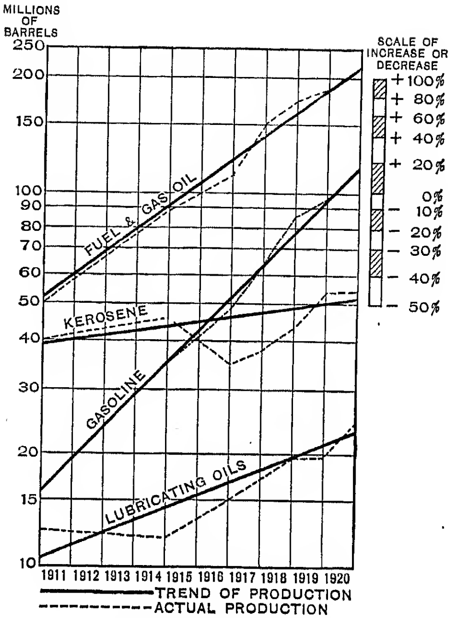


Fig. 70.—The relative growth in output of the four principal petroleum products in the United States, 1910–1920.

Trend of Fuel Oil Production.—The rate at which the production of fuel oil and gas oil has been increasing in the United States during the past decade, compared with the increase of gasoline, kerosene, and lubricating oils, is shown graphically on a ratio scale in Fig. 70. It will be observed that the straight line fitted to the curve for fuel oil is steeper than the trends of kerosene and lubricating oils, but less steep than the trend of gasoline. The relative volumes of the four products turned out during the same period are depicted in Fig. 71. The sharp rise in gasoline demand (Fig. 70) is seen to have notably restricted the output of kerosene (Fig. 71), and to have begun to exert a similar effect upon the production of fuel oil.

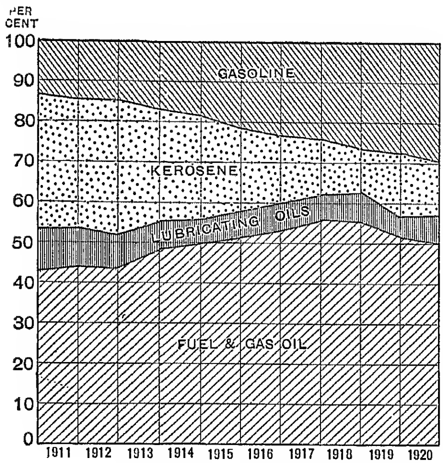


Fig. 71.—The relative proportions of the four principal petroleum products produced in the United States, 1910–1920.

TABLE 63.—SUMMARY OF THE GAS AND FUEL OIL SITUATION

Period	Production, Millions of Gallons	Stocks,* Millions of Gallons	Exports, Millions of Gallons	Domestic Consumption, Millions of Gallons	Average Domestic Price, Dollars per Barrel	Average Export Price, Dollars per Barrel
By years: 1914	3734	....	703	....	0.90	1.15
1915	....	....	812	....	.72	1.16
1916	4664	....	964	....	1.04	1.19
1917	6513	578	1124	....	1.57	1.70
1918	7321	659	1201	6039	2.01	2.33
1919	7627	714	618	6954	1.59	2.22
1920	8861	847	847	7891	2.79	2.78
By months:						
1919. January	590	646	75	528	1.88	2.53
February	554	693	37	471	1.60	2.10
March	575	749	37	482	1.55	2.31
April	589	808	46	485	1.44	2.16
May	652	789	43	629	1.40	1.97
June	632	812	54	564	1.37	2.15
July	638	818	45	587	1.37	2.15
August	686	830	39	635	1.40	1.91
September	683	862	39	612	1.44	2.08
October	680	829	66	649	1.49	2.34
November	663	791	82	619	1.62	2.36
December	685	714	57	705	2.53	2.14
By months:						
1920. January	618	652	75	605	2.33	2.10
February	590	590	52	600	2.33	2.05
March	687	580	68	629	2.88	2.25
April	643	591	78	554	2.93	2.81
May	707	619	70	609	3.24	2.67
June	690	642	68	599	3.18	2.89
July	751	655	79	659	3.12	2.88
August	834	709	59	721	3.11	3.31
September	837	771	60	714	3.02	3.33
October	823	799	93	703	2.74	3.08
November	823	809	65	748	2.44	2.96
December	859	837	84	747	2.13	3.16
By months:						
1921. January	837	921	110	643	1.92	3.26
February	733	993	73	588	1.44	2.36
March	758	1005	69	677	1.39	2.85
April	813	1056	72	690	1.39	2.48
May	817	1163	51	659	1.23	2.52
June	826	1249	62	678	1.08	2.09

* End of period.

Current Trend of Supply and Demand.—The trend of the major factors entering into the interplay between supply and demand is shown by months for the period 1917–1921 in Fig. 72, the supporting data being presented in Table 63. The outstanding features of the chart are: The distinctly complementary relationship between stocks

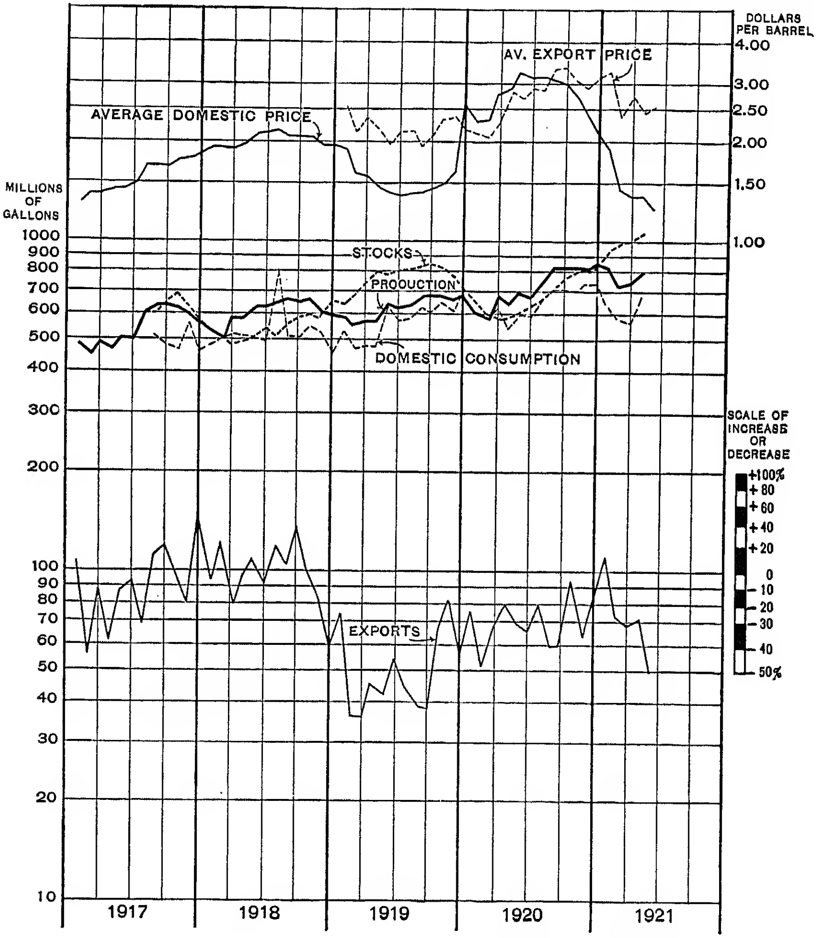


FIG. 72.—Trend of the gas and fuel oil situation in the United States by months, 1917–1921.

and price; the tendency for production to show a marked seasonal variation in conformance with the demand for gasoline; and the degree to which exports have fallen away since 1918.

Relation of Production to Stocks.—The size and trend of production by months compared with the stocks of fuel and gas oil on

TABLE 64.—PRODUCTION AND STOCKS OF GAS AND FUEL OIL IN THE UNITED STATES BY MONTHS, 1919–1920, CLASSIFIED BY REFINERY DISTRICTS

Data from U. S. Bureau of Mines

(In millions of gallons)

Period	East Coast		Penn., etc.		Ind., Ill., etc.		Okla., Kan., etc.		Tex., La.		Wyo., Colo., etc.		California		Country	
	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks
1919. January	81.9	129	13.0	26.8	34.3	34.3	105	118	152	146	22.0	23.8	181	168	590	646
February	83.5	136	12.1	27.3	29.9	34.1	102	140	135	156	18.6	21.6	173	178	554	693
March	75.9	146	14.1	26.1	32.7	37.7	96.8	160	146	174	22.6	18.8	186	187	575	749
April	75.8	122	13.0	28.4	41.1	43.8	98.4	177	140	185	23.7	23.7	197	228	589	808
May	97.7	107	12.6	27.3	45.4	46.8	114	192	157	204	23.0	23.5	203	188	652	789
June	110	105	12.4	25.3	40.0	44.0	111	191	160	223	24.7	23.3	175	201	632	812
July	107	97.7	15.1	25.0	39.8	40.4	104	196	157	241	23.9	27.5	192	191	638	818
August	111	98.1	13.6	24.1	44.6	39.3	97.2	200	190	226	22.0	27.1	208	216	686	830
September	111	98.4	12.6	24.7	41.2	40.9	108	203	169	239	28.3	27.7	214	228	683	862
October	110	75.1	14.5	25.7	44.5	38.8	112	205	176	235	25.2	29.0	197	221	680	829
November	115	67.7	16.9	26.7	43.4	30.2	106	189	172	232	24.7	25.2	185	220	663	791
December	147	71.3	19.3	22.4	43.8	24.7	104	154	159	206	20.9	19.2	191	216	685	714
Year	1226	.....	169	.....	480	.....	1259	.....	1912	.....	280	.....	2301	.....	7627	.....
1920. January	112	58.6	16.2	20.5	45.3	24.8	98.6	129	153	184	16.0	17.4	176	218	618	652
February	107	52.8	14.7	16.7	45.5	25.1	99.1	102	151	156	15.8	18.0	156	219	590	590
March	130	56.6	14.5	13.7	42.1	21.0	103	90.8	199	160	16.1	16.7	182	221	687	580
April	131	62.0	17.0	16.2	44.1	25.0	93.2	101	170	134	15.7	17.9	172	235	643	591
May	161	82.2	16.7	18.5	43.6	25.2	109	104	186	150	18.5	20.2	173	219	707	619
June	148	96.3	19.2	19.5	37.6	21.1	114	117	180	151	17.6	20.2	173	217	690	642
July	143	99.5	17.5	22.8	55.2	35.1	124	132	205	147	18.0	20.1	189	198	751	655
August	171	109	23.8	36.1	59.9	35.4	133	140	224	178	18.8	22.9	203	188	834	709
September	203	127	19.9	34.5	52.7	39.3	127	157	222	214	18.3	25.0	193	174	837	771
October	191	140	17.2	34.8	50.0	45.9	122	152	235	254	18.4	25.4	189	147	823	799
November	220	149	15.9	37.6	44.5	47.1	108	146	224	265	18.0	25.7	192	139	823	809
December	224	157	14.8	34.3	43.0	46.8	106	164	243	311	21.6	28.3	207	96.4	859	837
Year	1942	.....	208	.....	564	.....	1338	.....	2392	.....	213	.....	2206	.....	8861	.....

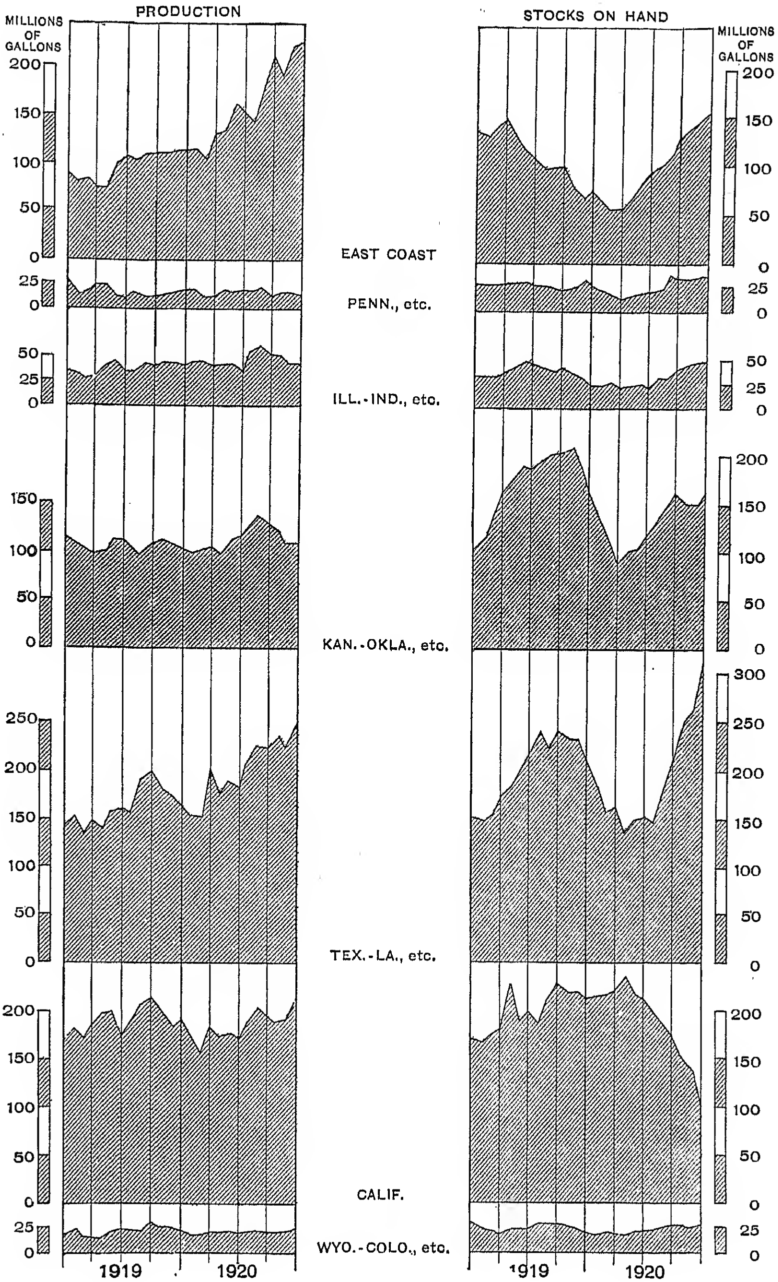


FIG. 73.—Production and stocks of gas and fuel oil in the various refinery districts of the United States by months, 1919–1920.

hand in the various refinery districts in the United States for 1919 and 1920 are shown graphically in Fig. 73, with the supporting data given in Table 64. The chart brings out the marked increase in production during 1920, especially on the East Coast and in Texas-Louisiana, compared with a general increase in stocks over the same period. The stocks on hand in California, however, display a sharp departure from this tendency in the latter part of 1920.

Analysis of Demand.—Fuel oil is used mainly for fuel in the industries and for transportation. Much of the power employed in the Pacific States and the Southwest is generated by this liquid fuel. The East is less dependent upon fuel oil, although the extension of its use here has also been rapid. The advantages of oil over coal are many and well known (see Fig. 74) and need not be detailed here.

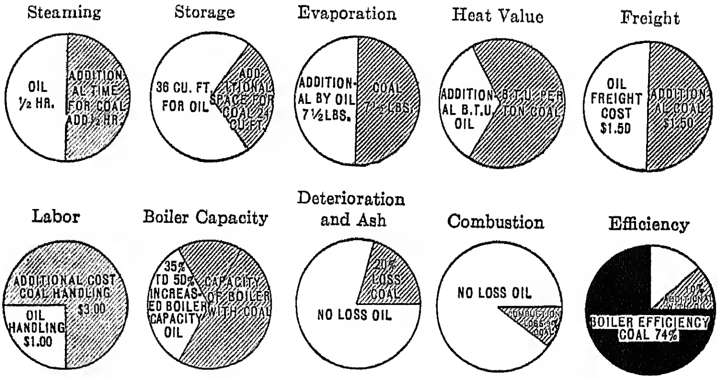


Fig. 74.—Graphic comparison of the efficiency of coal and oil as fuel; after Tide Water Oil Company.

Granted a bountiful supply at a low price, its field is as wide as that of coal itself.

Fuel oil is the principal energy dependency of industry and transportation in the far West. The absence of an adequate supply and the relatively high price of coal make fuel oil a highly important factor in the entire Pacific coast region. An adequate supply of petroleum is probably of greater importance for the Pacific Coast than for any other section of the country, as it constitutes the principal or only source of fuel for heating purposes, marine and river navigation, railways, public utilities, and for mining and manufacturing activities (see Fig. 75). The petroleum industry of California supplies most of the fuel needs of Arizona, California, Nevada, Oregon, and Washington (see Fig. 76). The extent of the far-western dependency upon an exhaustible resource has turned active attention to the development of water-power in this region,

and hydroelectric installations have not only greatly increased in recent years but would appear to offer the principal avenue of relief to the eventual decline of California's oil-fields.

Detailed information on the consumption of fuel oil in the rest of the country is wanting, but a rough division of the supply into principal uses is shown in Fig. 77, prepared from data for 1918.[1] It will be of interest to appraise the trend of the most important demands, having in mind that if the supply proves inadequate requirements of lower economic standing will have to go by default in favor of those of higher economic rank.

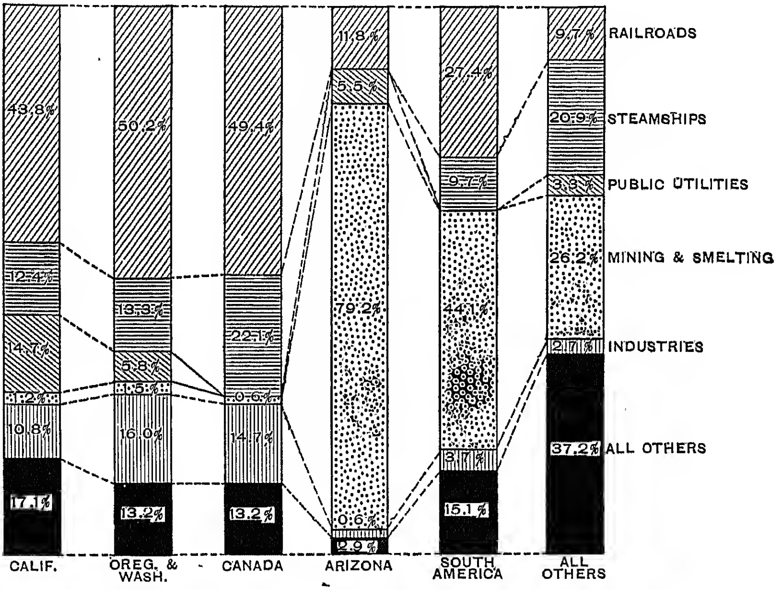


FIG. 75.—Utilization of California fuel oil in 1917 by territories and types of uses; data from California State Council of Defense.

Demand by Marine Transportation.—The merchant shipping of the world is rapidly turning to fuel oil as a source of power. The advantages to be derived from liquid fuel in the place of coal are so outstanding in facilitating bunkering, increasing the radius of steaming, and conserving labor in firing, that this trend will undoubtedly increase rapidly, especially in view of the highly competitive situation developing between the merchant marines of Great Britain and the United States. The shift from coal to oil in the marine field has been spectacular. The new construction in shipping occasioned by the submarine ravages during the war has served to accentuate

[1] Kindly supplied by G. B. Richardson, U. S. Geological Survey.

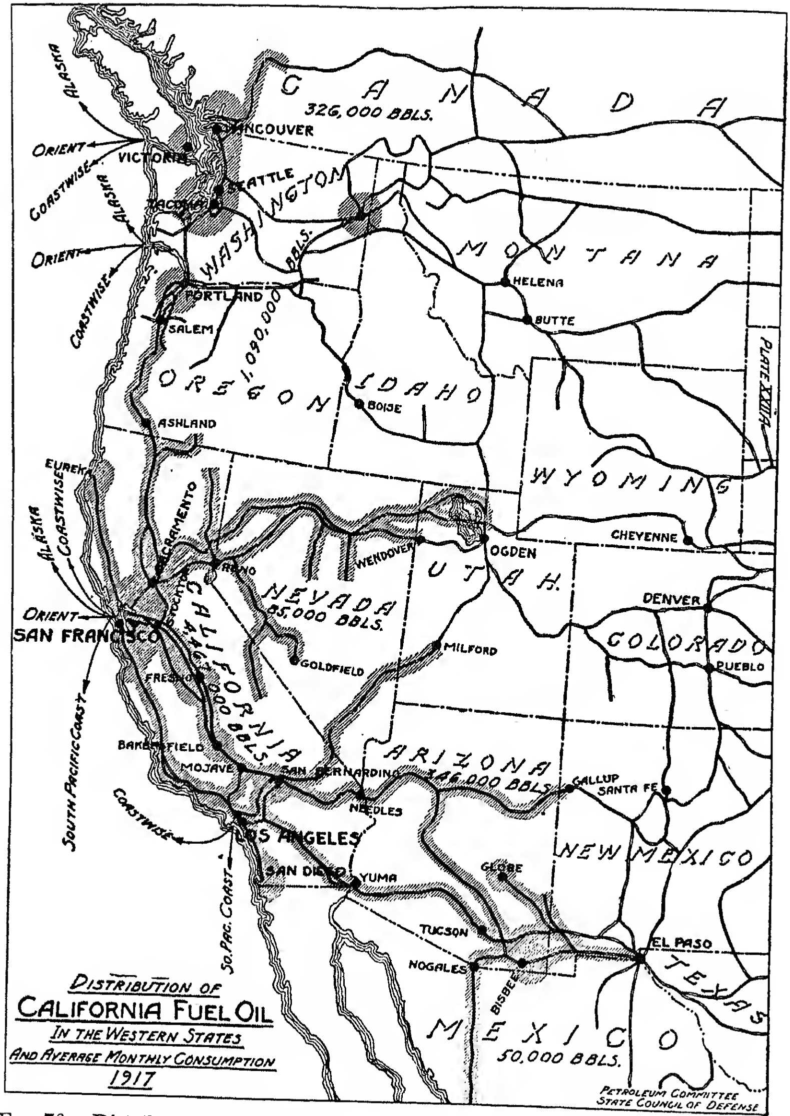
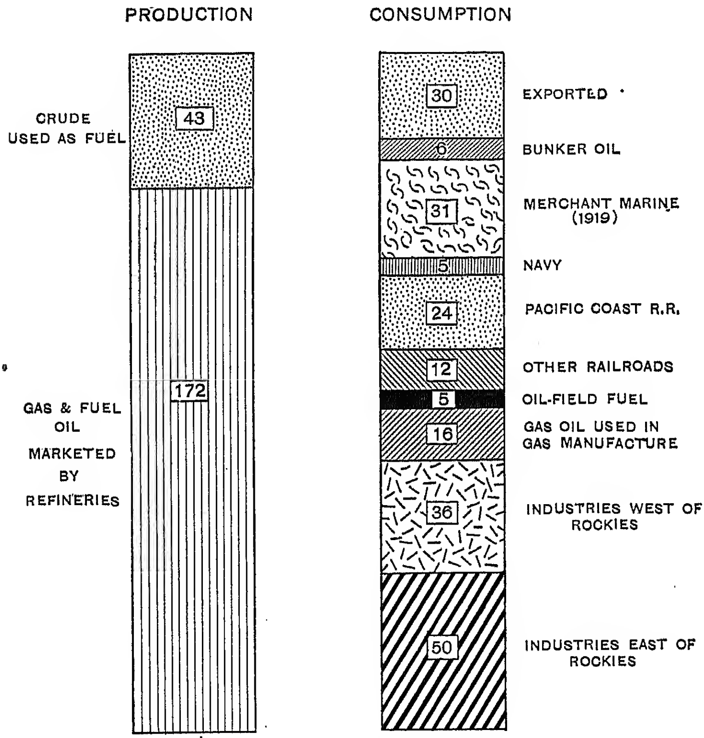


FIG. 76.—Distribution of California fuel oil in the western states; after California State Council of Defense.

the change. At the beginning of 1921 the world's merchant shipping approximated 55 million tons. Of this tonnage, around 9 million tons is already on an oil-burning basis, of which nearly a million tons is fitted with Diesel engines. Expressed in terms of oil, this shipping when fully employed represents an annual fuel oil demand of approximately 90 million barrels. The rate of change from coal to oil may be judged from the fact that of the total world tonnage in 1918–1919,



Figures are Millions of Barrels.

FIG. 77.—Consumption of fuel oil in the United States in 1918 by types of uses.

12 per cent was fitted to use oil, while in the following year the proportion had increased to 18 per cent. (See Table 65.)

The shift from coal to oil is being accomplished in two directions: By the conversion of coal-burners tooil-burners, and through the construction of motor vessels. The second aspect of the situation is just beginning to come effectively into bearing in the United States; but construction of motor ships in Great Britain and on the continent of Europe is proceeding apace. While the motor ship using oil has a strong advantage over the oil-fired steamer in point of

economy, evidently much of the world's shipping will make the transition to oil through an intermediate stage of oil firing, which means for the present that 10 million barrels of fuel oil may be roughly estimated as the requirement of each million tons of shipping dependent upon oil.

TABLE 65.—CLASSIFICATION OF THE WORLD'S TONNAGE OF SHIPPING BY TYPES OF FUEL

Data from Lloyd's Register of Shipping, 1919–1920 *

	1918–19, Per Cent	1919–20, Per Cent
Coal as fuel	82	76
Fitted to use oil fuel for boilers	10.5	16.3
Fitted to use oil in internal-combustion engines	1.5	1.7
Sail power only	6	6
	100	100

* Compiled by The Naval Annual, 1920–1921, London, p. 180.

An analysis of the vessels turned out and under construction by the U. S. Shipping Board shows that the merchant marine of the United States is substantially on an oil-burning basis, as indicated by Table 66. The commitment of the Shipping Board to an oil-fired policy has already had a marked effect upon the fuel oil market. The requirements of the Board in 1920 were upwards of 30 million barrels. And while the industrial depression of 1920–1921 greatly curtailed this demand, the vigorous resumption of international trade may be expected to revive and intensify the fuel requirements in the marine field.

TABLE 66.—TONNAGE PRODUCED AND UNDER CONSTRUCTION BY U. S. SHIPPING BOARD, NOVEMBER, 1920 *

	Constructed, in Thousands of D. W. T.	Under Construction, in Thousands of D. W. T.	Total, in Thousands of D. W. T.	Per Cent
Oil-burners	4159	422	9269	49.4
Coal-burners	2141	18	4581	23.3
Coal or oil (convertible)	2245	283	2159	27.3
Total	8544	724	2528	100.0

* Data from U. S. Shipping Board.

In recent years there has been a rapid growth in the quantity of fuel oil laden on vessels engaged in foreign trade, which increased from 14 million barrels in 1919 to 26 million barrels in 1920. A considerable portion of the total was used by vessels flying foreign flags and in a sense constituted foreign shipments. Data covering the quantity and price of this oil in 1919 and 1920 by important groups of ports appear in Table 67.

TABLE 67.—QUANTITY AND VALUE OF BUNKER OIL LADEN AT U. S. PORTS ON VESSELS ENGAGED IN FOREIGN TRADE IN 1919 AND 1920

Data from U. S. Bureau of Foreign and Domestic Commerce

	Quantity, Millions of Barrels		Value, Dollars per Barrel	
	1919	1920	1919	1920
Atlantic Coast ports.........	8.41	16.7	2.37	2.80
Gulf Coast ports............	2.32	3.95	1.67	2.37
Pacific Coast ports..........	3.29	5.64	1.69	1.86
All U. S. ports..............	14.0	26.3	2.09	2.53

In addition to the merchant shipping requiring oil, the navies of the world are already largely on an oil-burning basis. The advantages of oil over coal for naval operations are too outstanding to be denied. While the naval demand is small in comparison with the requirements of merchant shipping, about 5 million barrels annually for the American Navy, this demand is a most insistent one and must be met irrespective of price.

On the whole, it is evident that oil for merchant marine transportation has assumed important proportions, and the strength of this demand is such that if necessary it can divert from industrial purposes the quantity needed for shipping requirements.

Demand by Railroad Transportation.—Fuel oil is used in large quantities by the railroads of the United States; and in the Far West railway transportation is largely dependent upon this fuel. The geographical distribution of the railroad demand for fuel oil is shown in Table 68, while the growth in the demand from 1909 to 1920 is indicated in Table 69. The advantages of oil over coal for railway transportation are not so outstanding as with marine transportation. Yet sufficient advantage is present to make it probable that in event of shortage the railway demand will rank distinctly above industrial demand in the price it can afford to pay for oil fuel in competition

with coal. In this general connection it should be borne in mind that motor locomotives are a possibility, but their development would serve merely to raise the status of the demand, as is true in the matter of motor ships.

TABLE 68.—DISTRIBUTION OF THE RAILWAY DEMAND FOR FUEL OIL IN THE UNITED STATES IN 1919 AND 1920

Data from American Petroleum Institute

(In millions of barrels)

Section	1919	1920
Eastern	0.12	0.03
Southern	0.87	1.03
Middle West and Southwest	11.6	15.6
Southwestern Pacific	18.1	20.6
Northwestern	4.52	4.45
Total	35.2	41.8

TABLE 69.—GROWTH IN THE CONSUMPTION OF FUEL OIL BY AMERICAN RAILROADS, 1909–1920

Data from U. S. Geological Survey and American Petroleum Institute

(In millions of barrels)

1909	19.9
1910	23.8
1911	29.7
1912	33.6
1913	33.0
1914	31.1
1915	32.8
1916	38.2
1917	42.2
1918	36.7
1919	35.2
1920	41.8

Demand by Public Utility Power Plants.—Public utility power plants in the United States consumed 13 million barrels of fuel oil in the production of electricity in 1920, as compared with 11 million barrels in 1919. The geographical distribution of this consumption is shown in Table 70.

TABLE 70.—CONSUMPTION OF FUEL OIL BY PUBLIC UTILITY POWER PLANTS IN THE UNITED STATES DURING 1920, BY STATES

Data from U. S. Geological Survey

(*In thousands of barrels*)

California	5625	Mississippi	110
Texas	2883	Alabama	97
Kansas	821	Arkansas	84
Florida	631	Wyoming	82
Louisiana	488	Nebraska	80
Missouri	449	New York	39
Oklahoma	346	Maine	31
Rhode Island	321	Connecticut	26
Georgia	312	South Dakota	25
Arizona	239	Oregon	24
Massachusetts	153	Others	73
Washington	143		
		Total	13,082

Demand by Automotive Transportation.—Up to the present automotive transportation has been supported almost exclusively by the volatile products of the petroleum industry. An increasing quantity of distillate fuel oil, however, is now converted into gasoline, and this item will continue to enlarge and make growing inroads upon the fuel oil supply. In addition, internal combustion engines using superior grades of fuel oil are coming into play, and a significant portion of the heavy traction element of automotive transportation may ultimately pass substantially to a heavy-oil basis. Oil refiners are already meeting this tendency with the production of special distillates designed for internal combustion engines of the injection type. Once under full swing the heavy-oil automotive engine may come to represent a very large requirement. The fuel oil supply is thus under requisition in two directions as a source of motor-fuel, and so insistent may such demands be expected to become in the future, that the product will gradually be diverted from most of its present applications and brought increasingly into action as a support to automotive transportation.

Demand by Heavy-oil Stationary Engines.—The heavy-oil stationary engines of the Diesel and semi-Diesel types are coming into growing importance in the United States. No data are available for estimating the present consumption under this head, but in mines and for oil pipe-line pumping and irrigation work in the Middle and Far West, and for many light and power plants of small size,

there is an increasing utilization of this type of prime mover. It is certain that the heavy-oil engine already playing such an important part in power production in the older countries of Europe will enjoy a rapidly expanding use in the United States, and a significant demand for suitable types of fuel oil may therefore be anticipated on this score.

Demand for Gas Manufacture.—A considerable quantity of fuel oil is consumed annually in the manufacture of gas. In the Far West where coal is lacking, residuum fuel oil is used for the production of oil gas; but in the rest of the country distillate fuel oil under the name of gas oil is employed to enrich gas made from coal or coke. (See Table 71.) The demand for gas oil was easily met so long as

TABLE 71.—ESTIMATED CONSUMPTION OF GAS OIL IN THE MANUFACTURE OF CARBURETED WATER GAS AND MIXED GAS IN THE UNITED STATES DURING 1920 BY STATES *

Data from American Gas Association

(*In thousands of barrels*)

New York	6928	Nebraska	153
Illinois	2185	Georgia	152
Pennsylvania	1976	Wisconsin	149
New Jersey	1332	Washington	122
Massachusetts	1072	Delaware	83
Michigan	555	Florida	76
District of Columbia	435	New Hampshire	63
Connecticut	388	Alabama	59
Missouri	343	South Carolina	58
Iowa	285	Colorado	36
Indiana	281	Ohio	38
Maryland	278	North Carolina	36
Minnesota	270	Tennessee	33
Texas	233	Maine	31
Virginia	202	South Dakota	30
Louisiana	184	Vermont	22
Rhode Island	177	Others	40
		Total	18,324

* Does not include approximately 4450 thousand barrels of fuel oil used in manufacture of oil gas in the Pacific States.

there was a surplus seeking an outlet in this direction. With the upgrowth of cracking, however, a shortage of gas oil developed, and the gas industry is deeply concerned with the ultimate effect of this change. The price of gas oil is now determined by the value of

motor-fuel, and the gas companies can obtain their accustomed supply only by entering into competition with automotive transportation. But since the price of gas is limited by public utility regulations, it seems probable that the gas industry will find increasing difficulty in paying a competitive price, and in consequence will be forced either to change their practice so as to use residuum fuel oil, which will tide them over for a time, or else gradually give up the employment of oil, which is not fundamentally essential with improved methods.[1] In fact, when properly reorganized along modern lines, the gas industry will not only be able to operate without contributions from the oil industry, but will actually be able to contribute light oils as a new source of supply to oil refineries. The conversion of coal into gas under by-product practice not only has this possibility for the immediate future, but changes in this direction are likely to come with some measure of rapidity.

Demand for Industrial Purposes.—Putting to one side the fuel oil employed for other purposes, there was left in 1918 about 86 million barrels for the use of industry. Of this quantity about 36 million barrels was consumed west of the Rocky Mountains, where industrialism has grown up dominantly on an oil-fuel basis. This left roughly 50 million barrels to satisfy the industrial demands east of the Rockies. While these figures have changed somewhat since 1918, they go to show that the industrial field is meagerly served by fuel oil, in spite of the great furor that of recent years has developed in regard to the industrial shift from coal to oil. It is evident on closely analyzing the resource that the trend in this direction has been greatly exaggerated. Of the fuel oil consumed for industrial purposes east of the Rockies, a considerable proportion is used in the metallurgical industries where oil serves a distinct and unique purpose. Counting off this portion, there is left a really insignificant quantity as compared with the hundreds of millions of tons of coal consumed in industry.

Under the conditions prevailing over the past few years, efforts were made to enlarge the eastern demand for fuel oil in railroad transportation and industry in competition with coal. This tendency was greatly accelerated during the war, and many came to see this outlet as the true direction in which fuel oil might come into its own. During the fall and winter of 1919–1920, in pursuance of the example of 1917–1918, widespread propaganda was put into effect in favor of oil as a substitute for coal. So vigorously was this idea pushed, and so uncritical were many in respect to its accomplishment, that the coal associations became apprehensive over the possibility

[1] See Chapter XXIII.

of serious inroads being made upon their industry, and arguments were even advanced to the striking miners at the time that the country was no longer fundamentally dependent upon their efforts in mining coal. The public was also led to expect that a new element had been introduced into the fuel situation, and that the growing smokiness of cities and the fuel troubles of New England, and so on, could be remedied by the newcomer, oil. The unsoundness of the general view that prevailed in the latter part of 1919 may be seen from Fig. 78, which shows the meagerness of the country's supply of fuel oil as compared with coal. To replace with fuel oil the coal consumed annually in the United States would require a production of crude petroleum of upwards of 3 billion barrels, a quantity sufficient to exhaust the entire domestic petroleum reserve in two years.

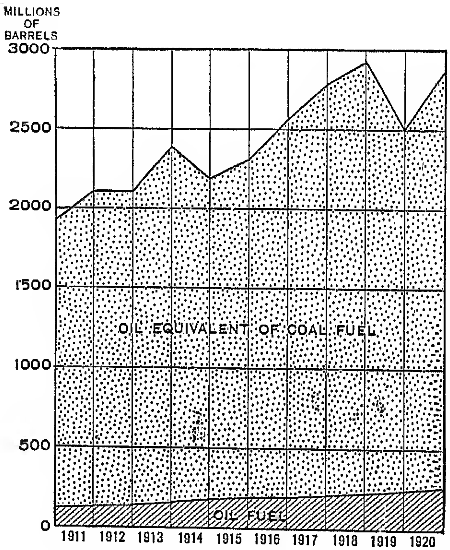


FIG. 78.—The relative importance of coal and oil as fuel in the United States, 1910–1920.

Demand for Domestic Purposes. — In connection with the efforts directed toward the substitution of oil for coal in industry, there was considerable planning in favor of widespread domestic consumption of fuel oil, especially in New York and New England. Such a project, however, may be regarded as an incidental offshoot of the general agitation, and there is no prospect of significant developments of this kind, in view of the fact that the domestic demand must of necessity take what is left after commercial requirements are satisfied.

Summary of Demands.—It would seem from this recital that the manifold demands for fuel oil are simultaneously enlarging at the same time that the factors influencing the supply of fuel oil are losing force. Among the multiplicity of demands crowding in upon the supply of fuel oil, a great variety exists as regards economic strength, which is one way of saying that certain of these demands can afford to pay more for fuel oil than can others. Where such is the case,

and shortage develops, lower demands must go by default in favor of higher requirements. On this basis, residuum fuel oil will gradually disappear from the market, augmenting the supply of motor-fuel and increasing the output of special distillates adapted primarily to the needs of the heavy-oil engine. These changes may be expected to come into play rather quickly, so that a matter of a few years may see the fuel-oil situation quite radically at variance with that obtaining in 1921.

Conclusion.—Fuel oil offers such a range of advantages over coal for ocean shipping, and such high economy can be effected through the use of the heavy oil motor, that the world's shipping is rapidly turning or planning to turn to this ideal fuel. In view of the limited nature of the resource, this tendency, once under full swing, may be expected to bring an advance in price such as will largely withdraw the product from its industrial fuel rôle, especially since the demand for gasoline at the same time will be pulling more and more heavily upon fuel oil through the avenue of cracking. As soon as fuel oil is fairly caught between the pressure of this twofold motor demand, its availability for purely industrial purposes on land in competition with coal will rapidly become a thing of the past. Fuel oil to the present has remained cheap only because of its production in advance of the growth of demands adjusted to its real possibilities.

It is questionable, however, if the world's resources in petroleum can support for more than a transient period widespread shipping operations on an oil-fuel basis. Ultimately automotive transportation on land may be expected to come into direct competition with marine transportation for petroleum supplies, and then the economic advantage now in favor of petroleum fuel oil for ocean shipping will be forced back to the side of coal in some form.

CHAPTER XII

LUBRICATING OILS

Introduction.—Of the various products derived from petroleum lubricants represent the most intricate and perplexing to describe. The manufacture and application of lubricating oils is an art rather than a science; little reliable published knowledge exists in this field, and a dearth of scientific investigation has been accorded it. Even among practical lubricating men, there is no uniformity of practice or methods, and diverse opinions are available on almost every point. The subject is complicated further by variations in the character of the crude petroleums from which lubricants are manufactured, by diversity in the types of refining employed in various parts of the country, and by an obscure and illogical nomenclature that adds to the confusion. The art of lubrication is still largely a matter of individual knowledge and trade secrets; and much remains to be desired in the way of accurate information on the subject.

Relation to Crude Petroleum.—The lubricating components of crude petroleum are a graded series of heavy hydrocarbons possessing sufficient viscosity, or body, together with certain other inadequately understood properties, to fit them for lubricating service. The quantity and character of the lubricating components recoverable vary with the type of crude petroleum employed. The paraffin-base petroleums upon proper treatment yield up to 25 per cent of lubricating oils; the asphalt-base petroleums, up to 40 per cent or so; while the mixed-base crudes run from perhaps 10 to 20 per cent.

In regard to the lubricating components of crude petroleum, Mabery states:[1]

"The next series of hydrocarbons, of the general formula, C_nH_{2n-2}, is found in all petroleum. Collecting in the fractions above 300° C. and having some viscosity, they form the lubricants in Appalachian petroleum that are prepared for sewing machines, typewriter machines, and for other similar light lubrication. The higher members of this series are also constituents of the heavy motor-car lubricants. Heavy petroleum, in general, is composed to a large

[1] Composition of Petroleum and Its Relation to Industrial Use, American Institute of Mining and Metallurgical Engineers, Publ. No. 158, Feb., 1920, p. 4.

extent of these hydrocarbons; but although in such general use, their structure has not yet been ascertained.

Next in order is the series C_nH_{2n-4}, made up of hydrocarbons possessing a high viscosity; $C_{25}H_{46}$ is one of them. *These hydrocarbons form the constituents of the best lubricants it is possible to prepare from petroleum. Heavy petroleum with an asphaltic base contains these hydrocarbons in large proportion, and lighter varieties in smaller amounts.* With boiling points above 250° C. in vacuum, the decomposition, when distilled with dry heat, is partly prevented by the use of steam in the still or, better, by excluding air and reducing the boiling points by exhaustion when these hydrocarbons may be distilled repeatedly with but slight decomposition. Straight petroleum lubricants are, therefore, made up mainly of a few viscous hydrocarbons of the last two series mentioned, and they are graded by varying the mixtures to provide for the kind of lubrication desired."

The lubricating components of paraffin crudes are lighter in weight and less volatile (vaporize at higher temperatures) than the lubricating components of asphaltic crudes; because of this fact, coupled with differences in the behavior of the associated paraffin wax and asphalt, the recovery of the lubricating content differs in the two types of crude. Thus the lubricating oils in paraffin-base crudes are only partly distilled off, the larger portion being recovered in the form of a residue; whereas with asphaltic crudes, the lubricating content is completely distilled off, leaving a residue of asphalt. This basic difference in lubricating yield gives rise to two main types of lubricating oils, residual lubricating oils (called cylinder stocks) and distillate lubricating oils (embracing all other varieties),—a distinction which has far-reaching economic consequences.

The bulk of lubricating oils in this country is still made from paraffin-base crudes, although there is a marked tendency of late to bring a growing quantity of mixed-base and asphalt-base crudes into lubricating production, especially since the Eastern paraffin crudes are running short of requirements. The dominant place held by the paraffin crudes in lubricating manufacture is due to the early availability of the Pennsylvania paraffin-base crudes and to their peculiar adaptability for yielding oils of sufficient body and heat resistance for utilization in steam-cylinder lubrication. Thus the paraffin crudes have largely determined the current practice in the refining and application of lubricating oils; and prevailing opinions on matters of lubrication are still largely colored by the historical precedence of the Pennsylvania crudes.

Relation to Refinery Practice.—There are two principal methods of refining in use in this country—steam distillation and dry, or destructive, distillation. The first is used where high-grade lubri-

cating oils are to be produced; the second causes some decomposition, or cracking, and is employed where a maximum yield of gasoline is sought without reference to lubricating output, although a lessened and inferior yield of lubricating oil may at the same time be gained. A full extraction of lubricating values reduces the output of the more volatile distillates such as gasoline and kerosene.

As the demand for lubricating oil increases, one refinery after another changes from destructive distillation practice in which the focus is upon gasoline, to steam distillation practice in which the prime objective is lubricating oil. Thus the refineries of the country may be classified into (*a*) skimming plants, in which the volatile distillates are hastily removed from the main body of the crude, which is thereby left in the form of residual fuel oil; (*b*) plants running to coke, wax, or asphalt, in which the practice has evolved to a fuller extraction of components, but with the focus still upon a maximum yield of light distillates, destructive distillation still dominant, and the yield of lubricating oil incidental or entirely lacking; and (*c*) plants running to lubricating oils, in which the main effort is directed toward the maximum yield and quality of these components.

According to figures compiled by the U. S. Bureau of Mines in January, 1921, skimming plants constitute about 35 per cent of the refinery capacity of the country; plants running to coke or asphalt, in which lubricating manufacture is lacking or merely incidental, about 19 per cent; and plants paying considerable attention to the production of lubricating oils, approximately 46 per cent. It is thus apparent that much of the refinery capacity has not advanced to lubricating output, as is indicated also by a recovery factor of only 5.4 per cent while the average lubricating content of the crude supply of the country is upwards of 25 per cent. A vast volume of potential lubricants is burned annually in the form of fuel oil.

Basic Types of Lubricating Oils.—Fundamentally there are two types of lubricants from which the numerous grades on the market are manufactured; these are residual lubricating oil (cylinder stock) and distillate lubricating oil. Residual lubricating oil is made from paraffin-base and mixed-base crudes by steam distillation only. Distillate lubricating oil embraces three main varieties: (*a*) non-viscous neutrals, made from all three types of crude by steam distillation; (*b*) viscous neutrals, of heavier body than the non-viscous neutrals, made from all three types of crude by steam distillation; and (*c*) paraffin oils, made from paraffin-base and mixed base crudes by destructive distillation. The relations of these major types of basic lubricants are shown in the following table:

TABLE 72.—PRINCIPAL TYPES OF LUBRICATING OILS

Types of Crude	Steam Distillation		Destructive Distillation
	Distillate	Residual	Distillate
Paraffin-base	Non-viscous neutrals Viscous neutrals	Cylinder stocks	Paraffin oils
Mixed-base	Non-viscous neutrals Viscous neutrals	Cylinder stocks	Paraffin oils
Asphalt-base	Non-viscous neutrals Viscous neutrals	....	....

Residual Lubricating Oil (Cylinder Stock).—Cylinder stock is the residue left after gasoline, kerosene, gas oil, and lubricating distillates have been distilled off from paraffin-base or mixed-base crudes. Practically all of the Eastern paraffin crudes are made to yield a maximum output of cylinder stock, but only a small portion of the Mid-Continent paraffin and mixed-base crudes are yet refined for this product. Asphaltic crudes do not produce cylinder stock, since their entire lubricating content may be distilled off, leaving a residue of asphalt instead of cylinder stock.

Cylinder stock is relatively highly resistant to heat, and in consequence is used for the lubrication of steam cylinders, a service which distillate lubricating oils are unable to render satisfactorily because of their lower heat resistance. Cylinder stock is also highly viscous, or heavy-bodied, as compared with the neutrals made from paraffin-base and mixed-base crudes (although distillate lubricants of comparable body may be made from asphaltic crudes), and hence is widely in demand as a blending agent for giving the requisite body to oils designed for the lubrication of heavy service engines, machines, and motors. Much of the cylinder stock produced is filtered to gain a bright, attractive color, a property which the consumer has been taught to fancy and deem essential.

Non-viscous Neutrals.—These oils are the light-bodied, low-viscosity distillates produced from paraffin-base and mixed-base crudes in connection with the manufacture of cylinder stocks, and from asphaltic crudes that are run to lubricating oils. They are used for the lubrication of light machinery, especially the spindles of textile mills; but, lacking sufficient body, they must be blended with more viscous oils for the general run of lubricating service. Produced in

greater quantities than required by light machinery, they are not in strong demand and their price is relatively low.

Viscous Neutrals.—These oils are distillates of heavier body than the non-viscous neutrals; they are produced from paraffin-base and mixed-base crudes which are run to cylinder stock, and from asphaltic crudes which are subjected to proper refining. The viscous neutrals of asphaltic origin include oils of higher viscosity than those made from the paraffin crudes, being partly comparable in body to cylinder stock. The viscous neutrals of paraffin origin lack sufficient body for heavy-service lubrication, and hence for many purposes are blended with cylinder stock. The heavier-bodied neutrals of asphaltic origin have sufficient viscosity to support their utilization in unblended form for heavy-service lubrication.

Paraffin Oils.—The so-called paraffin oils are lubricants incidentally recovered in processes primarily concerned with the maximum output of gasoline and kerosene. They are not quite equal in quality to the neutrals and stocks, since they are refined by destructive distillation which impairs the yield and quality of the lubricants recovered. The paraffin oils have been improved in many instances by better methods of manufacture, and although they may ultimately play a waning rôle, a large volume of such oils will undoubtedly continue to come on the market for a considerable period.

Blended Lubricants.—The four major types of lubricating oils—non-viscous neutrals, viscous neutrals, cylinder stocks, and paraffin oils—may be used singly or appropriately blended. For light machinery, such as the spindles of textile mills, the non-viscous neutrals are usually employed, while the lubrication of steam cylinders demands a cylinder stock; but for the majority of applications a neutral or paraffin oil is mixed with a cylinder stock, the function of the latter being to give the mixture sufficient body, or viscosity. For the better class of lubricating service, such as high-grade machinery and internal combustion engines, the paraffin oils are not regarded as adequate; hence much of the lubricating demand, including most of the high-grade (most profitable) portion, draws its requirements from the neutrals and cylinder stocks. The growth of industrial activity, during the past years in particular, has not only increased the demand for lubricating oils of all kinds, but the development of better grades of machinery and new types of engines has thrown a relatively greater demand upon the neutrals and cylinder stocks, to the growing exclusion of the paraffin oils and inferior types; at the same time that the trend of lubricating requirements has been in the direction of more viscous oils, to the projection

of a growing burden upon cylinder stocks, upon which the attainment of any considerable degree of viscosity has heretofore been dependent. In short, the demands for the various types of lubricating oils have been growing at different rates, with a strong swing toward oils of greater viscosity, and this tendency has been met by increasing use of blended oils, particularly mixtures of neutrals and cylinder stocks. In this wise, cylinder stocks, which are preferred for steam-cylinder lubrication because of their resistance to high temperatures, have come generally to be regarded as essential to the manufacture of high-grade lubricants of all other types requiring considerable body.

Development of Lubricants from Asphaltic-base Petroleums.—While the changes in demand noted above were taking place, the growing production of asphaltic crudes, in the face of a slowing output of paraffin crudes upon which lubricant manufacture had been dependent, was stimulating the upgrowth of processes and refineries capable of making neutral oils from crudes which earlier were deemed fit only for yielding fuel oil. There is now an appreciable and increasing output of neutral oils of asphaltic-crude origin, and the neutrals so made cover a range of viscosities corresponding not only to the viscosities of the neutral oils made from paraffin-base crudes, but partly to those of cylinder stocks as well. In fine, so far as viscosities are concerned, the asphaltic crudes yield distillate lubricating oils of nearly as wide a scope as the combined distillate and residual lubricants obtained from the paraffin-base and mixed-base crudes.

Since lubricating practice was established and developed on the basis of paraffin crudes, the introduction of lubricating oil of asphaltic-crude origin has naturally been handicapped by an immature technology and a prejudiced market. The majority of practical oil men, brought up in the paraffin school, are reluctant to see any virtue in the newcomer, while oil men interested in the development of lubricants from asphaltic crudes are naturally strong advocates of their products. In consequence not only is there no unanimity of opinion on this point in the oil business, but two distinct and opposing points of view prevail—a situation that may be found even within a single company. The published and privately expressed opinions of the leading petroleum chemists and technologists in the country, however, are practically unanimous in asserting that for all purposes other than steam-cylinder lubrication the lubricating oils made from asphaltic crudes are inherently as serviceable as those made from paraffin crudes.

The Supply of Lubricating Oils.—The production of lubricating oils in the United States by refinery districts for the years 1918, 1919,

and 1920 is shown in the following table, while the data for 1920 are presented graphically in Fig. 79:

TABLE 73.—PRODUCTION AND PERCENTAGE YIELDS OF LUBRICATING OILS IN THE UNITED STATES, 1918–1920

Refinery District	1918		1919		1920	
	Production, Millions of Gallons	Per Cent of Total Oil Run to Stills	Production, Millions of Gallons	Per Cent of Total Oil Run to Stills	Production, Millions of Gallons	Per Cent of Total Oil Run to Stills
East Coast	257	8.6	280	8.2	329	8.5
Pennsylvania, etc.	183	21.0	181	19.0	190	19.3
Illinois, Indiana, etc.	97.5	7.7	102	6.2	126	6.3
Kan., Okla., etc.	110	3.7	93.2	3.3	91.2	3.0
Texas, Louisiana	123	3.4	121	3.0	203	3.9
Wyoming, Colorado	3.65	0.53	3.48	0.41	14.6	1.46
California	66.9	2.0	65.6	1.9	92.1	2.7
Total	841	5.33	847	4.92	1047	5.37

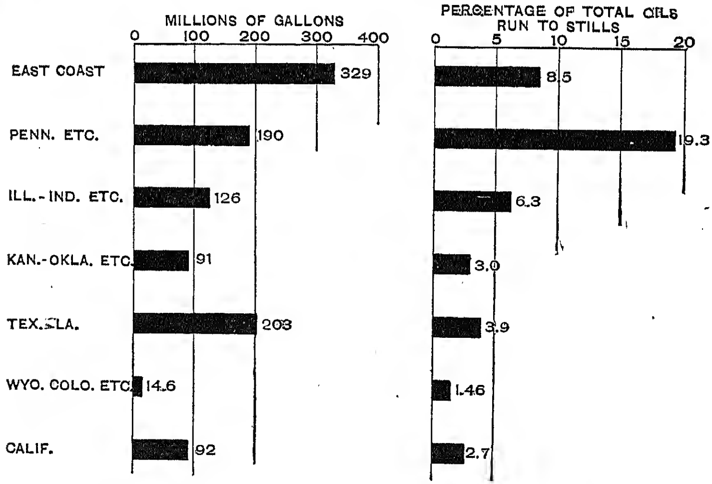


FIG. 79.—Output and percentage yields of lubricating oils in the United States by refinery districts in 1920.

It may be seen from these exhibits that while the bulk of the lubricating oil is manufactured in the East, a notable and growing quantity is made in the Middle and Far West. The percentage yields are also seen to vary between wide limits—from 19.3 per cent

in the Pennsylvania district, where lubricants have been longest manufactured, to 1.46 per cent in Wyoming, of recent note as an oil producer. These variations are another reflection of the great volume

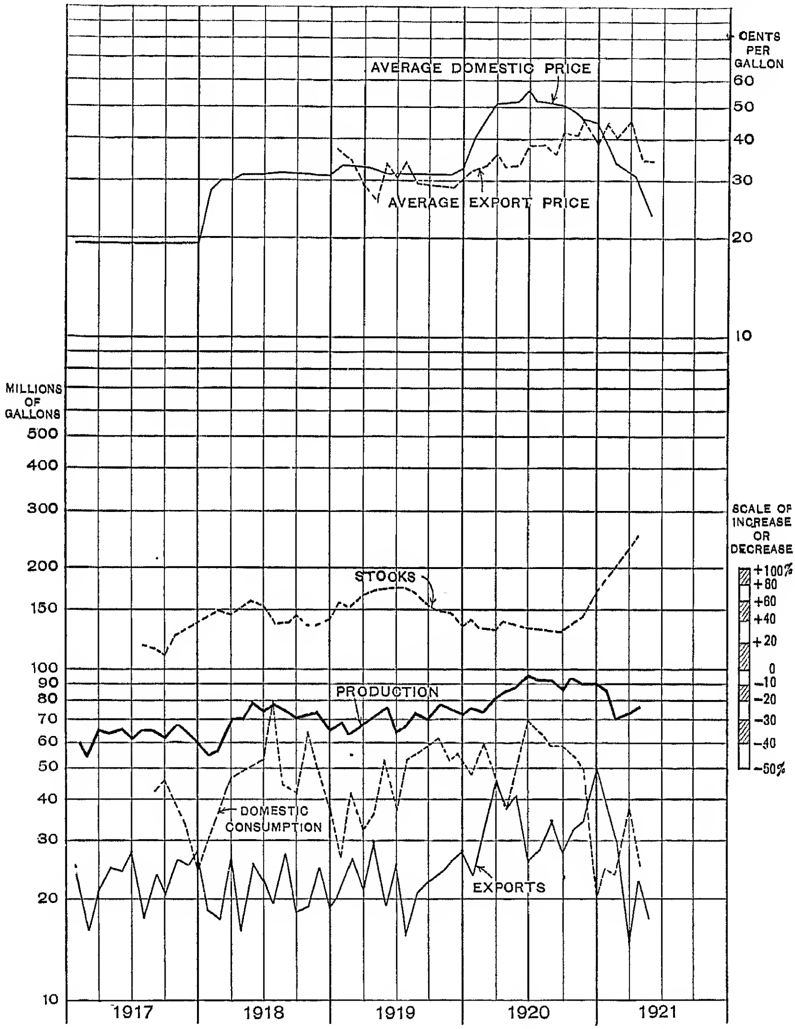


FIG. 80.—Trend of the lubricating oil situation in the United States by months, 1917–1921.

of crude petroleum used from which the lubricating content is not extracted.

Trend of the Current Situation.—The trend of the major factors entering into the current interplay between the supply and demand

TABLE 74.—SUMMARY OF THE LUBRICATING OIL SITUATION

Period	Production, Millions of Gallons	Stocks,* Millions of Gallons	Exports, Millions of Gallons	Domestic Consumption, Millions of Gallons	Average Domestic Price (jobbing), Cents per Gallon	Average Export Price, Cents per Gallon
By years: 1914	517	....	192	....	15.6	13.7
1915	....	....	240	....	14.9	13.5
1916	624	....	261	....	18.3	16.5
1917	754	137	280	....	19.5	20.6
1918	841	139	257	582	30.9	29.4
1919	847	137	275	574	32.2	30.9
1920	1047	161	411	612	48.9	38.0
By months:						
1919. January	68	158	22	27	33.3	36.5
February	63	152	27	42	33.2	34.6
March	67	165	21	33	32.5	28.9
April	71	170	30	37	32.4	26.4
May	76	174	19	53	31.8	33.0
June	65	175	25	39	31.9	30.7
July	67	174	16	52	31.9	34.1
August	73	171	21	57	31.7	29.8
September	70	159	22	60	31.6	29.1
October	79	153	24	61	31.6	28.9
November	76	149	26	54	31.6	28.9
December	72	137	28	56	32.7	30.9
By months:						
1920. January	76	142	24	47	39.5	32.1
February	74	133	33	50	45.4	33.8
March	82	131	44	40	50.8	36.4
April	86	140	39	37	51.4	33.6
May	89	136	42	52	51.7	33.9
June	95	133	27	66	55.7	38.5
July	92	132	28	65	52.1	38.5
August	91	131	34	58	51.4	37.8
September	86	130	29	57	50.0	41.4
October	93	136	33	55	48.6	40.9
November	91	142	34	51	46.0	46.0
December	91	161	51	21	44.9	39.5
By months:						
1921. January	86	184	38	25	38.6	44.1
February	72	202	30	24	33.6	40.2
March	73	223	15	37	31.1	43.5
April	76	250	23	26	29.9	35.4
May	70	262	17	51	23.8	34.6
June	63	261	15	49	23.8	29.8

* End of period.

of lubricating oils is shown in Fig. 80. The outstanding features of this chart are: The marked rise in production and exports in 1920; the sharp advance in price during the first half of 1920, followed by a steady fall the second half; and the declining stocks over much of 1919 and 1920. The supporting data for Fig. 80 are given in Table 74.

Relation of Production to Stocks.—The volume of lubricating oils produced monthly in the various refinery districts of the country during 1919 and 1920, compared with the stocks on hand, is shown graphically in Fig. 81. The advance in output of Texas-Louisiana in 1920 over 1919 attests the growing attention latterly devoted to lubricating manufacture on the Gulf Coast. The size of the stocks in the East is worthy of especial note, as well as the general tendency for the stocks in all sections of the country to increase in the closing months of 1920. The data entering into Fig. 81 are given in Table 75.

No recent figures are available for the country at large showing the output of the various types of lubricating oils, nor the relative degree to which the stocks of these types have accumulated. Information of this kind would be of the highest value in indicating the future course of the lubricating market. Partial information of this character is available, however, in the U. S. Census of Manufactures and is presented in the table following:

TABLE 76.—PRODUCTION OF LUBRICATING OILS IN 1914 AND 1919 BY TYPES

Data from U. S. Census of Manufactures

Type	Production				Value	
	Millions of Gallons		Per Cent of Total		Cents per Gallon	
	1914	1919	1914	1919	1914	1919
Pale or paraffin....	93	123	18	15	8.7	22.9
Red or neutral.....	116	211	22	26	10.7	21.2
Cylinder oils.......	103	235	20	29	13.3	25.1
Others............	205	250	40	30	10.7	25.8
Total..........	517	819	100	100	10.8	24.0

The Demand for Lubricating Oils.—The demand for lubricating oils during the past five years has not only been increasing in quantity, but shifting in character. The growth of demand is indicated approximately by the country's output of lubricants, since pro-

TABLE 75.—PRODUCTION AND STOCKS OF LUBRICATING OILS IN THE UNITED STATES BY MONTHS, 1919–1920, CLASSIFIED BY REFINERY DISTRICTS

Data from U. S. Bureau of Mines

(In millions of gallons)

Period	East Coast		Penn., etc.		Ind., Ill., etc.		Okla., Kan., etc.		Tex., La.		Wyo., Colo., etc.		California		Country	
	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks
1919. January	21.6	64.4	13.8	33.5	8.58	15.3	10.2	11.1	7.21	25.2	.286	.274	6.67	8.63	68.3	158
February	19.9	62.7	12.0	25.2	7.62	16.3	10.4	12.3	7.53	25.2	.203	.206	4.84	10.4	62.5	152
March	21.6	65.5	14.5	25.8	8.72	19.4	7.00	16.2	9.14	26.7	.261	.248	5.80	11.6	67.1	165
April	19.5	68.4	15.3	28.2	12.0	20.7	10.4	13.4	7.43	26.2	.242	.237	6.13	13.0	71.0	170
May	21.2	70.1	15.9	29.2	11.0	19.9	11.6	14.4	10.0	26.6	.168	.203	6.46	13.3	76.4	174
June	20.5	72.3	14.7	29.3	4.06	19.2	9.34	14.7	10.1	26.2	.156	.211	5.76	13.6	64.6	175
July	21.1	72.6	15.0	28.4	8.33	18.9	5.39	14.3	10.2	24.4	.261	.270	5.65	15.1	67.0	174
August	27.6	73.2	16.1	28.3	8.87	15.6	5.43	14.1	9.73	22.9	.215	.199	4.97	16.2	72.9	171
September	26.1	71.3	15.9	27.9	8.42	11.8	5.67	14.1	9.71	19.3	.298	.465	4.12	14.2	70.2	159
October	27.6	67.5	16.3	26.5	9.30	13.3	7.62	13.7	13.3	18.6	.530	.188	3.94	12.7	78.7	153
November	25.7	60.4	15.5	27.7	19.4	14.1	6.10	14.6	13.0	18.5	.491	.316	4.71	13.5	76.0	149
December	26.8	52.3	15.8	27.1	4.65	14.5	4.01	13.4	13.8	18.4	.370	.276	6.57	11.4	72.0	137
Year	280	.....	181	.....	102	.....	93.2	.....	121	.....	3.48	.....	65.6	.....	847	.....
1920. January	25.4	51.5	14.8	26.5	7.16	14.4	5.64	14.6	15.3	19.6	1.01	.636	6.58	14.6	75.9	142
February	24.1	47.5	13.2	26.0	8.31	15.1	6.90	11.4	13.1	20.2	1.30	.508	7.32	12.0	74.2	133
March	27.4	48.3	15.3	25.0	8.47	13.5	8.33	9.14	14.5	19.8	.928	.643	6.96	14.2	81.8	131
April	29.6	50.9	15.9	28.3	7.50	14.6	9.62	11.6	15.0	20.1	1.07	.598	6.92	14.2	85.6	140
May	29.8	47.6	16.7	29.9	8.78	12.7	8.26	10.6	16.4	18.5	.964	.326	8.36	16.2	89.3	136
June	26.8	50.0	16.9	29.7	16.7	12.2	8.30	9.50	18.1	18.7	1.39	.436	6.77	12.6	95.0	133
July	28.2	50.3	15.7	29.2	11.3	12.0	7.07	9.26	20.6	16.2	1.50	.585	7.94	14.4	92.4	132
August	25.2	49.6	17.4	30.5	12.2	11.8	7.96	8.82	20.1	16.5	1.31	.619	7.00	13.0	91.1	131
September	26.0	50.7	15.3	29.8	11.3	12.9	7.04	8.86	17.2	18.1	1.37	.551	7.97	9.60	86.2	130
October	28.9	48.9	16.3	28.7	11.7	15.1	7.44	9.62	18.3	19.5	1.38	.632	9.30	13.7	93.2	136
November	27.8	50.4	16.9	29.8	11.5	17.9	7.98	11.3	17.0	18.9	1.26	.929	8.79	13.0	91.2	142
December	30.3	53.4	15.6	32.3	11.4	22.4	6.69	14.1	17.4	22.8	1.11	.978	8.37	14.5	90.9	161
Year	329	.....	190	.....	126	.....	91.2	.....	203	.....	14.6	.....	92.0	.....	1047	.....

duction in a general way adjusts itself to demand. The shift in the character of demand, however, is of even greater significance and a view of this factor is presented in Fig. 82. With the data available it has been possible to divide the demand only into its principal com-

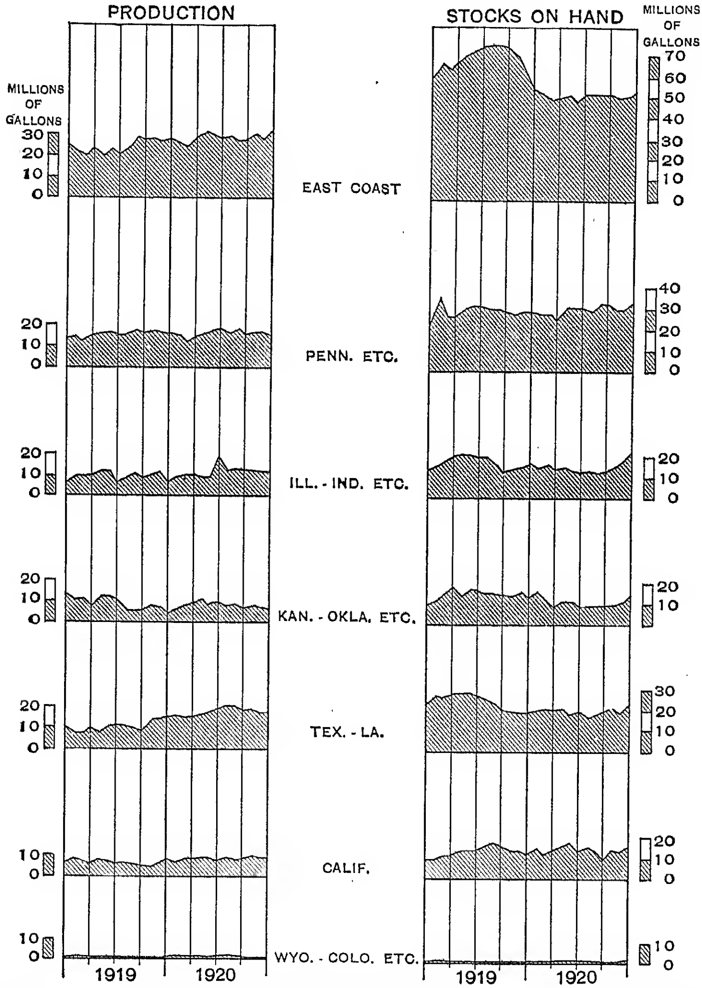


FIG. 81.—Production and stocks of lubricating oils in the various refinery districts of the United States by months, 1919–1920.

ponents—exports, railway consumption, industrial consumption, and automotive consumption. Such a division, however, is sufficient to show that automotive demand has cut sharply across the field, giving a new aspect to the situation. Close study of Figs. 82–85 will indicate more strikingly than words the relative importance of the various

demands and the highly significant position attained by the requirements of automotive transportation.

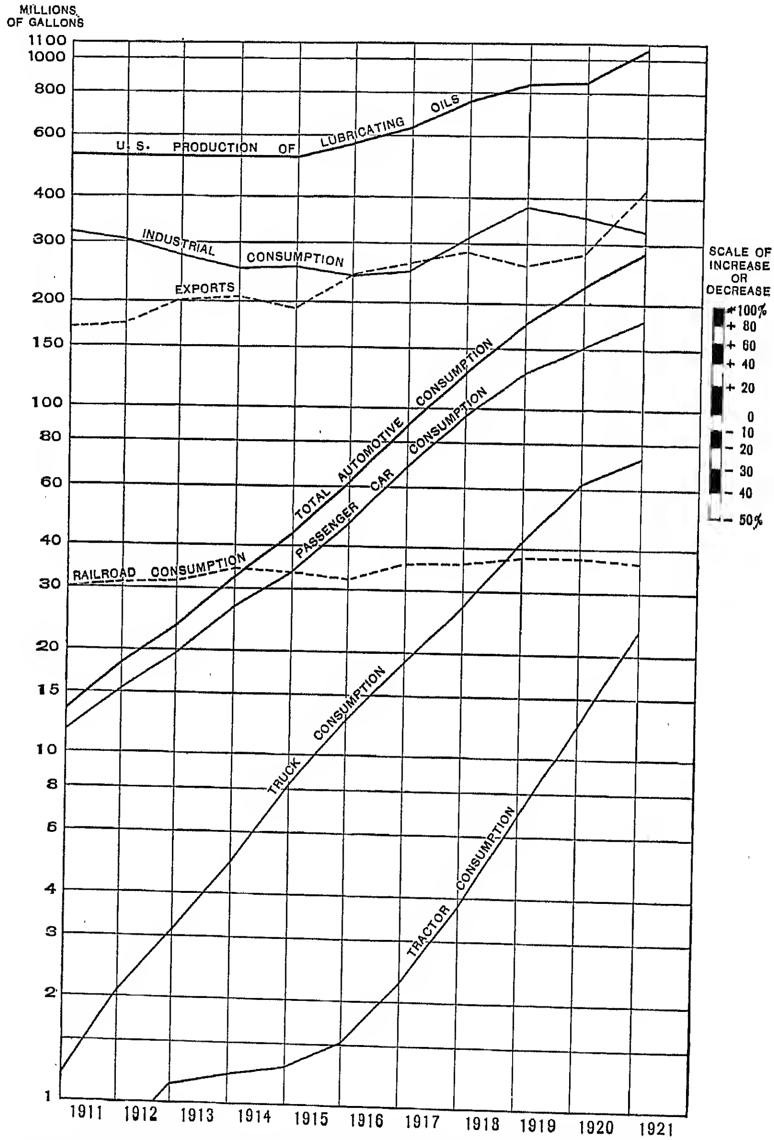


FIG. 82.—Trend of supply and demand for lubricating oils in the United States, 1910–1920.

Exports of Lubricating Oils.—The growth in exports of lubricants during the past ten years is shown in Fig. 82, while Fig. 85 indi-

cates the size of exports as compared with the domestic consumption. Roughly, a third of our lubricating oil is sent abroad. A large proportion of the world's machinery is lubricated by American oil, 411 million gallons of lubricating oil being exported in 1920 for this purpose. As to the grades of oil sent abroad, a large proportion is cylinder stock, because the foreign practice, especially on the Continent, makes use of high-pressure, superheated steam demanding a high-grade, high-test cylinder stock. It has been stated that probably as much as 80 per cent of our cylinder stocks are exported. Whether or not this figure is correct, it is evident that a large share of our heavy-bodied lubricating oil and the cream of the American output goes into foreign trade. The bearing of this fact upon the domestic situation, and especially upon the course of lubricating prices is very significant. It is evident that the industrial rehabilitation of Europe is dependent upon a steady flow of lubricants from this country, since cylinder stocks are not manufactured from foreign crudes in significant quantities, nor can newly developed petroleum resources abroad come rapidly into lubricating production.

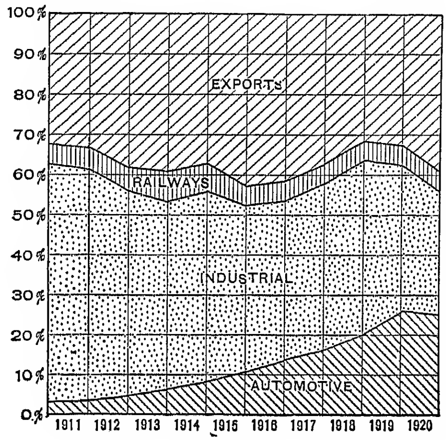


FIG. 83.—Percentage analysis of the demand for lubricating oils, 1910–1920.

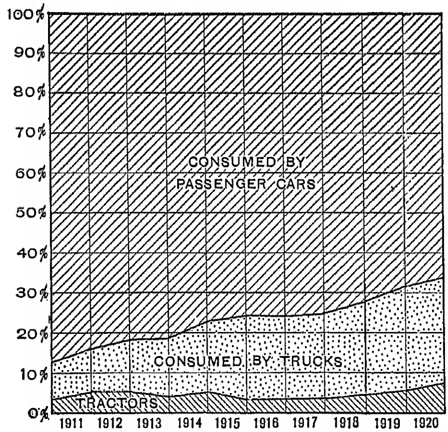


FIG. 84.—Percentage analysis of the automotive consumption of lubricating oils in the United States, 1910–1920.

The Railroad Demand for Lubricants.—The lubrication requirements of American railroads have been largely met by the products of

one company, and this condition still prevails though not to such an exclusive degree as was the case ten to fifteen years ago. The consumption of lubricating oils by American railways may be roughly estimated from data published by the Bureau of Corporations in 1906, and brought reasonably up to date on the basis of car mileage statistics issued by the Bureau of Railway Economics. While not exact, the results of this calculation are given in the following table:

TABLE 77.—ESTIMATED CONSUMPTION OF LUBRICATING OIL BY THE ROLLING STOCK OF THE UNITED STATES RAILWAYS

(Millions of gallons)

Year	Valve Oil	Engine, Coach and Car Oil	Total
1910	4.8	26.0	30.8
1911	5.0	26.2	31.2
1912	5.0	26.2	31.2
1913	5.5	28.7	34.2
1914	5.3	28.1	33.4
1915	5.2	27.1	32.3
1916	5.9	30.6	36.5
1917	5.8	30.6	36.4

It is apparent from this table and from Figs. 82, 83, and 85 that the railway consumption has not been increasing significantly and does not represent a highly important item in point of size as compared with motor oil or industrial lubricant consumption. It may be noted further that the bulk of the railway consumption is for the lubrication of bearings which does not require a high-grade oil.

The Industrial Demand for Lubricating Oils.—The quantity of lubricating oils consumed in the United States for industrial purposes has been approximately determined by subtracting from the total production each year the quantity exported and consumed at home by railways and automotive transportation. Reference to Figs. 82 and 85 will indicate that the industrial consumption, while increasing notably in 1917 and 1918, has fallen off slightly in 1919 and 1920. The industrial demand, however, is intimately connected with the industrial growth of the country and will increase in keeping with it, although the relative importance of the industrial demand compared with the requirements of automotive transportation may be expected for a time to decline, as indicated in Fig. 83.

The character of the industrial demand is changing somewhat,

due to the development of finer types of machines, the speedy growth of the electrical industry, the rapid development of steam turbine practice which is steadily replacing the reciprocating steam-engine in large installations, and the rapid upgrowth of the internal combustion engine in the stationary field. These changes, which for the present cannot be accurately measured, are, nevertheless, strikingly in a consistent direction, throwing a growing burden on the more

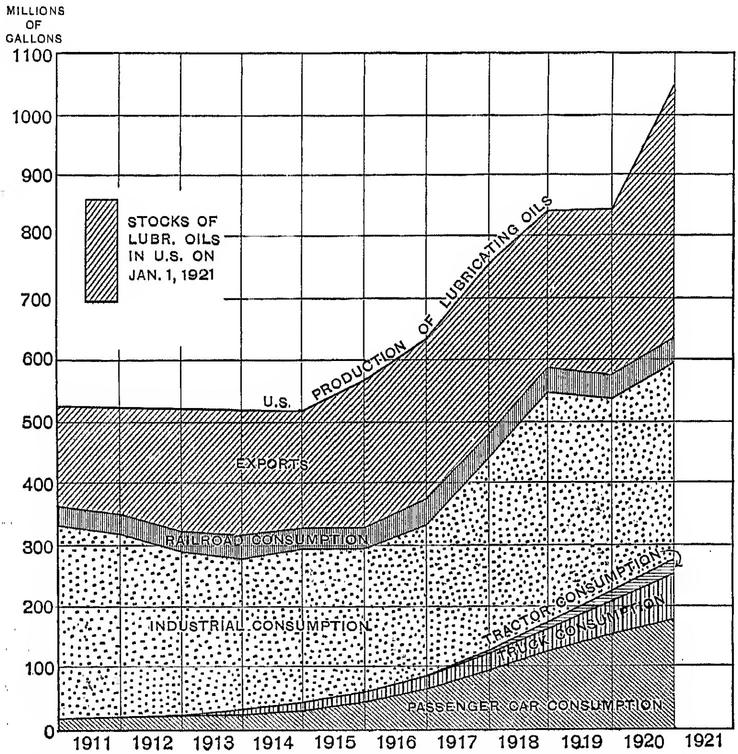


FIG. 85.—Analysis of the growth in the demand for lubricating oils in the United States, 1910–1920.

highly refined types of lubricating oils and upon the lubricants of heavier body. This unmistakable trend is reflected in a growing market for viscous neutrals and cylinder stocks, in contrast to non-viscous neutrals and especially the paraffin oils and other types made incidental to the manufacture of gasoline and kerosene.

The Automotive Demand for Lubricating Oils.—The phenomenal growth of automotive transportation is familiar to all, and the requirements of this field have occasioned a rapidly mounting pro-

duction of motor-oil. The significance of the motor-oil demand may be gathered from Figs. 82 and 85 where its striking rate of increase is graphically shown. The growth in motor-oil consumption has been calculated by multiplying the average number of cars, trucks and tractors in use by an appropriate consumption factor. The data are given in the following table:

TABLE 78.—AUTOMOTIVE DEMAND FOR LUBRICATING OILS

(000 omitted)

Year	Average Number Passenger Cars in Use	Gallons of Motor Oil Consumed Factor: 25 Gallons	Average Number Trucks in Use	Gallons of Motor Oil Consumed Factor: 75 Gallons	Average Number Tractors in Use	Gallons of Motor Oil Consumed Factor: 75 Gallons	Total Gallons of Motor Oil Consumption
1910	460	11,500	15	1,125	6	450	13,075
1911	610	15,250	27	2,062	10	750	18,062
1912	780	19,500	42	3,150	15	1,125	23,775
1913	1060	26,500	65	4,875	16	1,200	32,575
1914	1350	33,750	108	8,100	17	1,275	43,125
1915	1870	46,750	167	12,525	20	1,500	60,775
1916	2700	67,500	250	18,750	30	2,250	88,500
1917	3800	95,000	360	27,000	50	3,750	125,750
1918	5000	125,000	550	41,250	90	6,750	173,000
1919	6000	150,000	820	61,500	162	12,150	223,650
1920	7236	178,000	990	74,300	300	22,500	274,800

The accelerating demand for automotive purposes, which now represents about a quarter of the country's total output of lubricants and approximates the entire domestic industrial demand, is having a marked selective influence upon the lubricating market. Automotive lubrication requires principally four grades of lubricating oil—light, medium, heavy, and extra heavy—with a growing swing to the heavier grades brought about by the rapid increase of trucks and tractors, together with a growing appreciation of the fact that the general practice in the past has been in the direction of oils of inferior body. To meet the requirements of automotive transportation from lubricating oils manufactured from paraffin-base and mixed-base crudes, it has been thought necessary to blend cylinder stocks with viscous or non-viscous neutrals to gain the requisite body. This procedure placed an unexpected and unprecedented demand upon the heavy-bodied oils, namely, the cylinder stocks and especially the filtered varieties, with the result that a shortage of such products accompanied by a marked advance in their price developed early in 1920.

The growing stress falling upon the heavier-bodied motor-oils by virtue of the natural trend of automotive growth has been accompanied by a change in character of the fuel consumed. The decreasing volatility of gasoline caused by the incorporation of a growing proportion of heavy ends into the marketed product has given rise to a condition in which the lubricating oil in service is subjected to dilution, or thinning. This condition has contributed to the necessity for heavier-bodied oils, and the future would seem to indicate that the growing demand for motor-fuel will lead to further dilution and therefore swing the general practice in even greater degree toward heavier-bodied motor-oils.

TABLE 79.—ESTIMATED 1921 DOMESTIC DEMAND FOR MOTOR OIL BY MONTHS

Month	Per Cent of Year's Total Required Each Month	Millions of Gallons Required Each Month	Per Cent of Year's Total Required Each Quarter
January	5.4	15.5	
February	5.8	16.6	17.6
March	6.4	18.3	
April	7.2	20.6	
May	8.5	24.4	25.6
June	9.9	28.4	
July	11.2	32.2	
August	11.8	33.8	33.4
September	10.4	29.8	
October	8.8	25.2	
November	7.9	22.7	23.4
December	6.7	19.2	
Total	100	286.7	100

Seasonal Character of Automotive Demand.—The consumption of motor-oil displays a seasonal variation corresponding to the increased employment of motor vehicles in the warm months. The course of the motor-oil demand throughout the twelve months of the year follows closely the variations in gasoline requirements, and may be worked out on the same basis as that given on page 128. The seasonal curve will vary slightly from year to year according to the rate at which the demand is increasing. The estimated 1921 demand for motor-oil, distributed over the twelve months of the year, is shown in Table 79.

The estimate of the total demand is arrived at as follows:

	Millions of gallons
8.5 million cars at 25 gallons discounted 10 per cent.......	191
1.1 million trucks at 75 gallons discounted 10 per cent.....	73
0.3 million tractors at 75 gallons........................	23
	287

The numbers of cars and trucks are determined by averaging the registration figures for January 1, 1920, and January 1, 1921, in order to get the average number of units employed during the year. The normal gallonage is discounted 10 per cent to allow for a decreased utilization probable as a result of the industrial depression. The final results, of course, are only approximate, but are perhaps of sufficient accuracy to serve a useful purpose.

CHAPTER XIII

PETROLEUM BY-PRODUCTS

THE petroleum industry turns out four products of major importance—gasoline, kerosene, fuel oil, and lubricating oil, with many varieties falling under each head—and a number of additional substances which may be termed by-products. The most important of these by-products are paraffin wax, asphalt, coke, petrolatum, and grease. These products are used in their crude state and also form the basis for the manufacture of secondary products, an application particularly true of wax and petrolatum. The petroleum industry, therefore, affords an example of multiple production, the fabrication of expanding series of products from a single raw material.

The Development of By-products.[1]—Industries, such as the petroleum industry, engaged in the extraction of values from raw materials, have developed under the influence of demands for one or more products, and only under ideal conditions do those demands become so balanced as to cause a complete extraction of the values present, thus leading to full utilization of the raw material. Usually an industry in the early stages of its development produces one or more main products, and rejects what is left over as waste. This waste is regarded as a necessary accompaniment of production, and is discarded in lack of a demand calling for its use. As such industries develop, products of value come to be fabricated from the so-called waste, the activity then turning out by-products in addition to the main products, and less waste. But the development of by-products is a slow process, and an imposing loss of potential values accrues by this delay. When maturely developed, an industrial activity produces main products balanced in respect to demands, by-products fully developed to current needs, and no waste. There are few activities in the United States that have attained this measure of effectiveness.

In the course of industrial growth, the output of main products is under the control of a natural law whereby supply and demand seek mutually and automatically to affect a balance against disturbing

[1] For a detailed discussion of the economic rôle of by-products, see C. G. Gilbert and J. E. Pogue, The Energy Resources of the United States, Bull. 102, vol. 1, U. S. National Museum, pp. 95–97.

external factors. The production of waste and by-products, however, is under no such control, but is determined by the output of main products. Hence the supply of incidental products tends always to exceed the demand. Industry itself inclines to bring these products into use, but is limited by restrictive circumstances common to American economic practice. The industrial activity is often too small or poorly organized to make by-product recoveries, which usually gain their value from a cumulative effect possible only under large-scale operations. If the activity is financially strong and efficiently organized, it tends to build up by-products in so far as they are end-products that may enter immediately into consumption. Small pendent industries may even be added in order to make the conversion.

But if the potential by-products are of the intermediate order, requiring outside industries to carry them forward into use, and the requisite industrial activities are lacking, inadequate, or too foreign in scope to be built up by the parent activity, the whole matter gets beyond the reach of industrial stimulus. Such is the case with the majority of by-product possibilities. The parent industry can do little or nothing; independent activities to handle such materials are slow to develop, hampered by the uncertainties of a supply fluctuating independently of the pressure of their demands, hesitating to build at the mercy of conditions beyond their control.

But apart from these handicaps, where profits are readily attainable from the main products, there is little pressure forcing attention to by-product accomplishments. The loss involved in the non-development is not felt as such. Under pioneer conditions and in a new country richly endowed with opportunities for quantity production, the intricacies of by-product upbuilding are not apt to be thoroughly sounded.

TABLE 80.—PRODUCTION OF PARAFFIN WAX IN THE UNITED STATES

Year	In Millions of Pounds	In Percentages of Production in 1914
1899 *	256	67
1904 *	262	69
1909 *	313	82
1914 *	380	100
1916 †	386	101
1917 †	481	127
1918 †	505	133
1919 †	467	123
1920 †	541	142

* Census of Manufactures † U. S. Bureau of Mines

Such is the case with petroleum. Chemically without equal in its by-product possibilities, this substance has been developed with prime regard to its main products, and with but the merest beginning toward the realization of its by-product values.

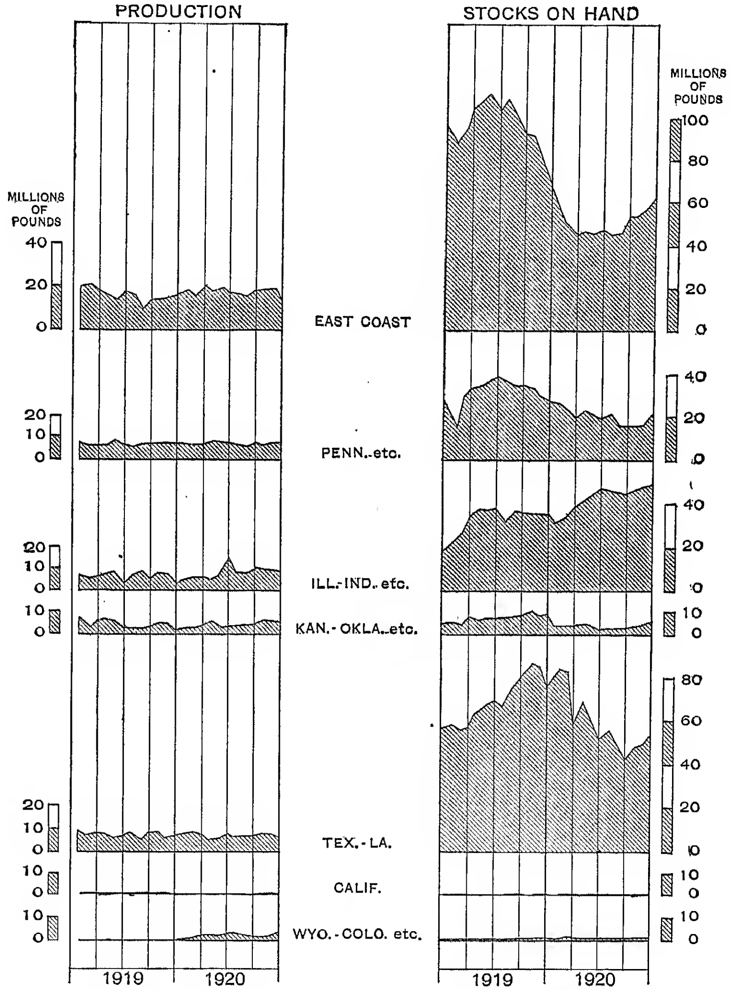


Fig. 86.—Production and stocks of paraffin wax in the various refinery districts of the United States by months, 1919–1920.

Paraffin Wax.—Paraffin wax is produced in large quantities because it must be removed in the refining of paraffin crudes from which lubricating oils are manufactured. In consequence, large supplies of this commodity have tended to accumulate, in spite of

TABLE 81.—PRODUCTION AND STOCKS OF PARAFFIN WAX IN THE UNITED STATES BY MONTHS, 1919–1920, CLASSIFIED BY REFINERY DISTRICTS

Data from U. S. Bureau of Mines

(In millions of pounds)

Period	East Coast		Penn., etc.		Ill., Ind., etc.		Kan., Okla., etc.		Tex., La.		Wyo., Colo, etc.		California		Country	
	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks
1919. January	19.8	85.4	7.34	15.8	5.69	23.2	4.56	5.34	7.25	58.4	.189	.663	.122	.217	45.0	189
February	19.7	90.7	7.57	29.8	5.45	27.5	3.45	5.05	6.19	56.5	.255	.254	.160	.214	42.7	210
March	17.1	102	7.45	32.9	6.23	34.5	4.98	7.82	7.14	57.5	.209	.258	.147	.280	43.3	236
April	16.9	105	7.52	35.5	6.49	37.3	4.52	7.18	6.34	63.3	.212	.470	.100	.377	42.1	249
May	13.4	109	8.00	37.3	7.59	37.7	4.57	7.97	5.41	67.0	.254	.492	.232	.504	39.5	260
June	17.4	101	6.59	38.1	2.11	37.1	2.58	7.76	5.97	69.3	.079	.506	.126	.670	34.8	255
July	15.7	107	6.31	36.4	6.75	36.5	2.43	8.21	6.89	66.2	.070	.609	.157	.674	38.3	255
August	9.55	99.2	7.57	34.4	7.90	37.2	2.50	8.58	3.00	75.5	.284	.642	.147	.598	30.9	256
September	13.3	91.5	7.42	34.2	5.64	36.3	3.41	8.85	6.35	80.2	.389	.784	.107	.576	36.6	252
October	14.0	89.9	7.00	32.5	6.89	36.0	4.15	10.4	7.51	87.0	.468	1.04	.284	.520	40.3	258
November	14.4	77.6	7.80	29.9	6.59	35.7	3.77	9.16	5.76	85.5	.363	1.14	.193	.666	38.9	240
December	15.6	63.3	7.15	27.9	2.07	35.0	2.86	9.04	6.65	76.9	.319	1.05	.252	.181	34.9	212
Year	187	.....	87.7	.....	69.4	.....	43.8	.....	74.5	.....	3.07	.....	2.03	.....	467	.....
1920. January	17.4	56.4	7.18	26.5	4.66	32.0	2.73	4.52	6.99	83.1	.726	.708	.320	.473	40.0	204
February	16.2	48.1	6.89	24.7	5.21	35.9	2.90	4.22	7.10	83.8	1.28	.920	.209	.434	39.8	198
March	19.6	45.7	7.22	21.0	5.59	39.0	3.72	4.35	6.51	56.6	2.05	.826	.202	.535	44.9	168
April	17.6	47.7	8.43	23.4	4.43	42.4	5.35	4.48	5.04	68.5	2.14	1.12	.351	.644	43.4	188
May	18.2	46.0	7.75	21.3	6.92	45.3	3.34	4.12	4.55	59.7	1.83	1.01	.177	.529	42.8	178
June	16.9	47.2	7.96	19.6	15.8	46.6	3.58	3.21	7.09	51.3	2.45	1.18	.156	.480	54.0	170
July	16.6	43.9	7.61	20.8	8.39	46.6	2.92	2.71	6.55	55.8	2.87	1.55	.259	.425	45.2	172
August	14.7	45.0	5.84	16.2	7.76	46.4	3.48	3.15	6.65	50.0	1.03	.682	.253	.487	39.7	162
September	18.1	51.7	7.67	15.9	8.50	45.4	3.57	2.95	6.76	41.4	1.86	.848	.249	.503	46.7	159
October	18.5	52.7	6.97	16.3	8.36	47.1	5.55	4.65	7.87	48.6	1.88	.833	.221	.313	49.3	170
November	18.3	57.5	7.84	17.2	8.54	48.1	4.38	5.37	7.65	49.9	2.08	1.31	.221	.338	49.0	180
December	14.8	62.3	7.66	20.9	8.71	48.6	4.97	6.58	6.56	54.9	3.68	1.63	.240	.498	46.6	195
Year	207	.....	89.0	.....	92.9	.....	46.5	.....	79.3	.....	23.9	.....	2.86	.....	541	.....

its rather ready application without intricate fabrication to a growing variety of uses.

The production of paraffin wax for the years enjoying a statistical record is shown in Table 80.

The production and stocks of paraffin wax in the various refinery districts in the United States are shown graphically by months for 1919 and 1920 in Fig. 86, with the supporting data given in Table 81. It is to be noted that the stocks relative to output are unusually large.

Asphalt.—Asphalt is mined in its natural condition and extracted from crude petroleum of asphaltic base. Native asphalt is obtained largely from the famous pitch lake in Trinidad. Petroleum asphalt is derived largely from California, Gulf Coast, and Mexican crudes.

The production and imports of asphalt of various types for the United States are given in Table 82.

TABLE 82.—MARKETED PRODUCTION AND IMPORTS OF ASPHALT BY YEARS, 1913–1920

Data from U. S. Geological Survey

(In thousands of short tons)

Year	Produced from Domestic Petroleum	Produced in U.S. from Mexican Petroleum	Domestic Production, Native*	Imports, Native
1913	437	114	93	207
1914	361	314	80	137
1915	665	388	76	135
1916	688	572	98	147
1917	702	646	82	187
1918	605	598	60	115
1919	615	675	88	105
1920†	688	1044	199	127

* Includes related bitumens
† Estimated.

The production and stocks of asphalt in the United States by months during 1919 and 1920 are shown in Fig. 87, the supporting data being given in Table 83. It is apparent that the bulk of the asphalt is manufactured on the East Coast (from Mexican petroleum), in the Gulf States of Texas and Louisiana, and in California.

Coke.—Petroleum coke is the residue left from the destructive distillation of crude oil. It is used as fuel and for the manufacture of electrodes. Its production in the United States by years from 1914 to 1920 is shown in Table 84.

TABLE 83.—PRODUCTION AND STOCKS OF PETROLEUM ASPHALT IN THE UNITED STATES BY MONTHS, 1919–1920 CLASSIFIED BY REFINERY DISTRICTS

Data from U. S. Bureau of Mines

(In thousands of tons)

Period	East Coast		Penn., etc.		Ill., Ind., etc.		Kan., Okla., etc.		Tex., La.		Wyo., Colo., etc.		California		Country	
	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks
1919. January	24.3	32.0	.212	2.81	7.87	8.08	.051	.018	12.0	41.3	.....	.033	9.60	8.85	54.1	93.0
February	19.3	39.1	.258	2.93	6.40	10.6	.024	.265	6.41	39.2	.009	.016	8.91	10.5	41.3	103
March	23.9	44.1	.043	2.89	7.09	15.2	.061	.268	9.37	38.6	.009	.016	9.69	12.8	50.1	114
April	23.8	50.4	.153	2.87	9.77	17.3	.008	.018	9.25	34.3	.....	.....	8.33	14.0	51.3	119
May	35.2	51.9	.235	2.87	10.6	15.7	.....	.018	17.1	37.5	.....	.011	10.8	13.6	73.9	122
June	35.7	45.5	.033	2.84	.402	9.78	.022	.016	21.3	37.5	.....	.011	15.7	12.8	73.2	108
July	37.9	43.4	.064	2.68	8.16	6.96	.....	.016	15.6	34.5	.....	.011	18.5	10.8	80.2	98.4
August	45.7	47.1	.116	2.65	5.36	4.87	.006	.022	21.1	32.6	.002	.011	18.4	10.0	90.7	97.3
September	43.9	34.6	.123	2.35	7.90	4.89	.....	.018	22.2	28.9	.....	.....	19.4	10.5	93.6	81.3
October	53.4	33.8	.166	1.94	8.42	3.54	.....	.018	25.9	27.3	.....	.....	18.0	9.85	106	76.4
November	52.2	31.9	.253	1.66	8.56	5.74	.....	.017	27.3	32.8	.....	.....	16.9	10.2	105	82.3
December	34.7	25.3	.459	1.12	10.8	4.13	.....	.017	23.1	33.7	.....	.....	13.3	9.25	82.4	73.4
Year	430	.....	2.12	.....	91.3	.....	.172	.....	211	.....	.020	.....	168	.....	902	.....
1920. January	28.5	24.0	.409	1.03	6.65	4.02	.....	.016	23.7	33.1	.....	.....	13.9	9.83	73.1	72.0
February	29.7	26.3	.236	.733	7.22	2.84	.....	.016	19.5	28.1	.....	.....	14.0	12.0	70.7	70.1
March	36.6	21.9	.464	.848	7.11	5.75	.....	.016	34.0	44.9	.....	.....	19.6	14.3	97.7	87.7
April	32.5	28.4	.561	.886	6.31	4.80	.....	.009	30.8	27.5	.....	.....	16.8	16.7	86.9	78.3
May	39.3	26.0	.586	1.02	7.99	3.74	.....	.009	31.9	26.2	.....	.....	22.6	14.3	102	71.3
June	49.9	26.5	.456	.692	12.7	3.10	.....	.009	30.8	9.47*	.....	.....	24.4	11.7	118	51.5*
July	57.2	24.1	.355	.549	9.86	4.53	.....	.263	38.2	30.9	.....	.....	23.3	11.0	129	71.4
August	63.0	18.5	.399	.457	9.95	6.29	.....	.239	44.9	34.0	.....	.....	25.7	8.72	144	68.2
September	66.0	21.3	.636	.848	10.2	5.67	.....	.191	40.2	38.1	.....	.....	24.5	8.85	142	74.9
October	59.8	21.3	.756	1.12	10.1	5.59	.....	.191	35.8	41.2	.....	.....	27.0	9.83	133	79.2
November	38.4	20.3	.408	1.15	10.9	6.98	.....	.192	26.7	41.2	.....	.....	24.8	10.6	101	80.4
December	38.8	22.0	.282	.857	11.0	5.76	.....	.191	22.2	41.0	.....	.....	19.8	11.3	92.1	81.1
Year	540	.....	5.55	.....	110	.....	.....	.....	379	.....	.....	.....	256	.....	1291	.....

* Figures Questionable.

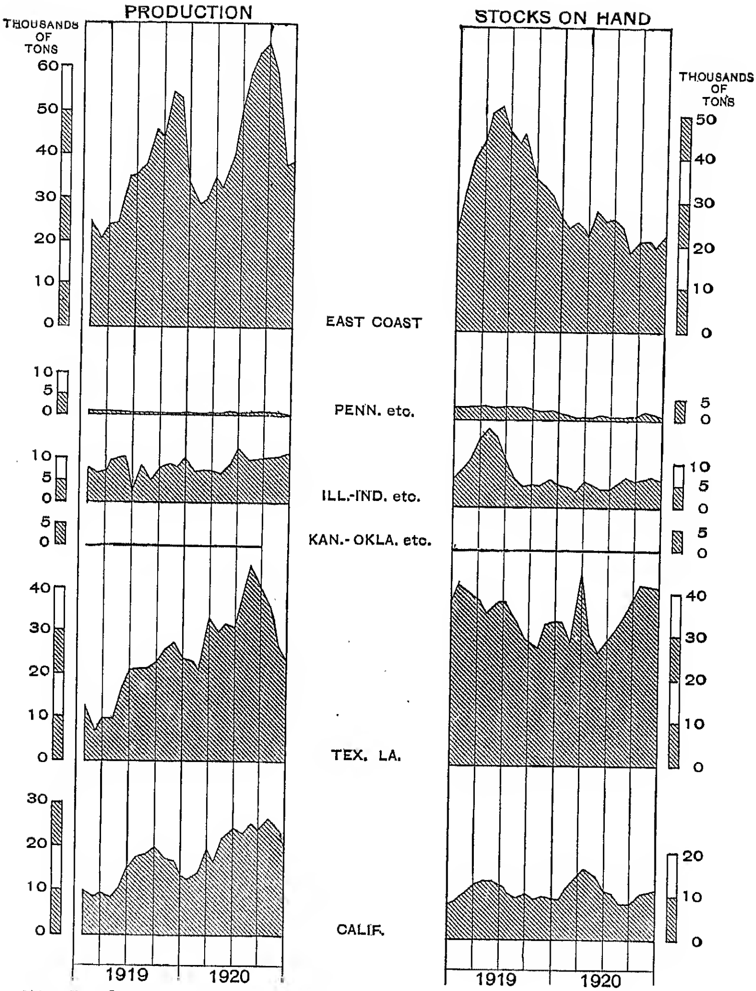


Fig. 87.—Production and stocks of petroleum asphalt in the various refinery districts of the United States by months, 1919–1920.

Table 84.—Production of Petroleum Coke in the United States

Year	In Thousands of Tons	In Percentages of the Production in 1914
1914*	214	100
1916†	405	189
1917†	539	252
1918†	560	262
1919†	603	282
1920†	577	270

* Census of Manufactures. † U. S. Bureau of Mines.

TABLE 85.—PRODUCTION AND STOCKS OF PETROLEUM COKE IN THE UNITED STATES BY MONTHS, 1919–1920, CLASSIFIED BY REFINERY DISTRICTS

Data from U. S. Bureau of Mines

(In thousands of tons)

Period	East Coast		Penn., etc.		Ill., Ind., etc.		Kan., Okla., etc.		Tex., La.		Wyo., Colo., etc.		California		Country	
	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks	Prod.	Stocks
1919. January	29.3	7.99	1.09	.637	10.9	3.46	5.71	6.18	10.2	7.11	1.73	3.35	.....	.....	59.0	28.7
February	28.0	10.2	1.44	1.26	10.3	5.72	4.19	4.24	11.2	7.65	2.10	4.61	.....	.....	57.2	33.7
March	26.6	10.0	1.81	1.36	10.9	7.96	6.41	8.71	10.5	5.45	2.42	4.15	.....	.....	58.6	37.6
April	15.4	12.4	1.65	1.46	11.2	8.67	5.19	11.0	10.6	7.68	2.27	4.41	.....	.....	46.3	45.6
May	18.4	9.81	1.81	1.55	14.8	7.67	5.50	11.4	8.21	6.63	2.35	4.63	.....	.....	51.0	41.7
June	16.6	9.82	1.71	2.41	7.36	7.07	3.83	12.4	9.93	6.81	1.90	4.85	.....	.....	41.4	43.4
July	18.9	9.66	.867	2.03	11.7	6.94	2.72	9.98	10.9	7.42	1.89	4.17	.....	.....	47.0	40.2
August	19.6	8.35	1.45	2.22	13.6	10.4	4.56	10.5	8.94	8.32	1.59	3.91	.....	.....	49.7	43.6
September	19.0	9.12	1.63	2.19	12.8	9.02	3.92	8.55	8.87	7.93	1.27	3.04	.....	.....	47.5	39.9
October	18.3	7.87	1.78	1.56	12.9	6.14	7.00	8.89	11.8	8.78	.831	1.60	.....	.....	52.6	34.8
November	19.0	9.39	1.39	1.13	12.5	7.23	4.74	6.34	12.1	7.15	.727	.698	.....	.....	50.5	31.9
December	19.9	9.16	1.54	.941	8.09	5.83	3.06	1.95	8.97	2.91	1.11	.364	.....	.....	42.6	21.1
Year	249	.....	18.2	.....	137	.....	56.8	.....	122	.....	20.2	.....	.....	.....	603	.....
1920. January	12.8	10.2	1.38	.914	9.99	7.01	3.03	2.43	10.8	.572	.566	.086	.....	.....	38.5	21.2
February	13.8	9.71	1.68	1.05	10.6	9.12	2.06	.546	8.65	.461	1.05	.825	.....	.....	37.8	21.7
March	17.0	4.92	1.32	.844	10.2	8.79	3.01	1.09	11.8	.413	1.05	1.49	.....	.....	44.4	17.5
April	17.0	5.44	1.58	1.43	9.29	9.72	2.78	1.48	9.39	.559	.525	1.06	.....	.....	40.6	19.7
May	16.4	5.33	1.12	1.13	11.3	8.67	2.12	1.78	9.44	1.39	.551	.546	.....	.....	40.9	18.8
June	16.0	4.99	1.24	1.17	23.8	8.70	4.59	1.03	10.6	3.08	.510	.385	.....	.....	56.8	19.3
July	16.8	2.87	1.31	.882	15.3	10.1	3.05	1.20	11.0	4.93	1.12	1.04	.....	.....	48.6	21.1
August	15.1	5.23	1.24	.860	15.5	10.3	3.49	1.70	9.44	7.25	1.48	1.81	.....	.....	46.2	27.1
September	17.0	2.85	1.60	.409	14.8	7.16	3.32	2.01	10.8	9.66	.836	1.43	.....	.....	48.4	23.5
October	20.8	3.96	1.95	.284	15.3	6.30	3.92	2.06	11.9	11.3	.453	.944	.....	.....	54.3	24.9
November	19.0	4.30	1.74	.488	17.1	6.32	4.49	3.42	12.9	10.5	1.75	.392	.....	.....	56.9	25.4
December	23.3	7.13	2.19	.236	17.7	6.92	5.40	5.68	13.6	11.3	1.05	.216	.....	.....	63.2	31.5
Year	205	.....	18.4	.....	171	.....	41.3	.....	130	.....	10.9	.....	.....	.....	577	....

The current trend of the production and stocks of petroleum coke by months for 1919 and 1920 is given in Fig. 88, with the supporting data in Table 85.

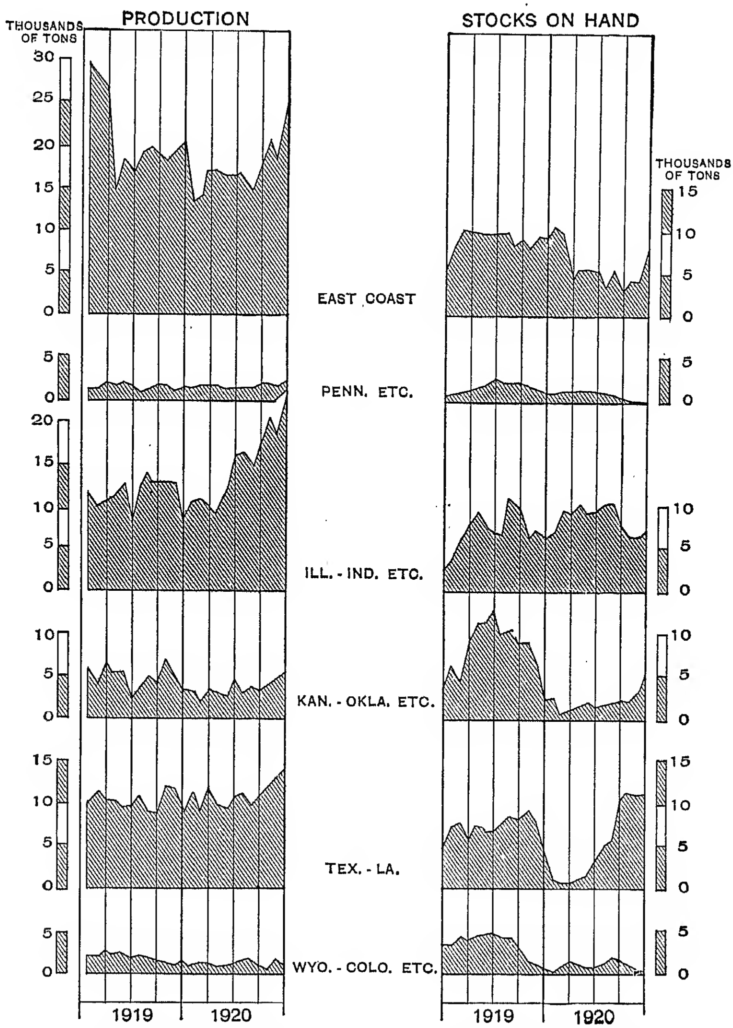


FIG. 88.—Production and stocks of petroleum coke in the various refinery districts of the United States by months, 1919–1920.

Petrolatum.—Petrolatum, the basis of vaseline and widely used in pharmaceutical preparations, is a petroleum product of especial interest by virtue of its extensive use in various fabricated forms. It is one of the few by-products of petroleum which has substantially

measured up to its capabilities. The production of petrolatum for a few recent years is shown in Table 86.

TABLE 86.—THE PRODUCTION OF PETROLATUM IN THE UNITED STATES

Year	Production, Millions of Gallons	Value, Millions of Dollars
1914*	6.07	1.24
1919*	10.23	3.75
1920†	6.79	....

* Census of Manufactures.

† U. S. Bureau of Mines. The product reported is not homogeneous with that given above for 1914 and 1919.

Prices of various grades of petrolatum in January, 1921, are shown in Table 87.

TABLE 87.—WHOLESALE PRICES OF PETROLATUM, JANUARY, 1921

Grade	Cents per Gallon
Snow white	18
Lily white	15
Cream petroleum jelly	12
Amber	7
Dark amber	6
Veterinary	5.5
Dark green	5.25

Greases.—There are no satisfactory commercial lubricants of hydrocarbon or fatty-oil origin that are sufficiently thick and otherwise suitable for the lubrication of all types of transmissions; hence it has been necessary to find a means of artificially thickening available oils to the desired consistency. Various types of greases (thickened oils) are manufactured to meet this need.

Greases are saponified fatty oils, of either animal or vegetable origin, which are combined with viscous hydrocarbon oils. Most trade-marked greases are scented and dyed. Greases are used for transmissions, gears, axles, and other types of lubrication requiring a highly viscous product. A characteristic grease is axle-grease; many products of this type contain mineral matter, such as mica or graphite.

The production of greases in the United States for the latest year for which figures are available is given in Table 88.

Table 88.—Production of Greases in the United States in 1914 and 1919

Data from U. S. Census of Manufactures

Types	1914			1919		
	Quantity, Thousand Gallons	Value, Thousand Dollars	Average Price, Cents Per Gallon	Quantity, Thousand Gallons	Value, Thousand Dollars	Average Price, Cents Per Gallon
Lubricating greases.	4980	1625	32.6	12,599	6044	48.0
Axle greases.......	2948	668	22.6	5,318	2103	39.6

Medicinal Oils.—Oils with medicinal properties are manufactured from petroleum in considerable quantities. Formerly such oils were obtained almost entirely from abroad, but the American products have almost supplanted the imported varieties. The production of medicinal oils in 1919 and 1920 is shown in Table 89.

Table 89.—Production of Medicinal Petroleum Oils in the United States, 1919–1920

1919	1,129,932 gallons
1920	1,375,081 gallons

The price of various grades of mineral medicinal oils in January, 1921, is shown in Table 90.

Table 90.—Price of Heavy White Mineral Medicinal Oil in January, 1921

Grade	Per Gallon
880–885 specific gravity...	$1.75
865–870 specific gravity...	1.20
850 specific gravity...	1.00

Miscellaneous Products.—The U. S. Bureau of Mines in its monthly reports on the refinery output of the United States includes a group of miscellaneous products. The composition of this group for the years 1919 and 1920 is shown in Table 91.

TABLE 91.—OUTPUT OF MISCELLANEOUS PETROLEUM PRODUCTS IN THE UNITED STATES, 1919–1920

Data from U. S. Bureau of Mines

(In thousands of gallons)

	1919	1920
Binder	1,685	1,786
Flux	31,285	34,710
Medicinal oils	1,130	1,375
Paint products	76	351
Petrolatum	6,421	6,794
Road oil	77,638	60,789
Roofer's wax	158	177
Sludge products	14,994	19,230
Acid oil	3,766	5,379
Bottoms	....	14
Distillates	571,238	787,685
Pitch	474	242
Residue	40	6
Slops	379	837
Tailings	19,326	5,907
Tar	3,545	4,682
Tops	108,956	107,901
Unfinished	376,229	451,267
Wash out	122	33
Wax tailings	3,017	3,417
Others	58,387	....
Total	1,278,864	1,492,584

The Future of Petroleum By-products.—A considerable range of by-products has already been manufactured from a portion of the crude petroleum brought into use; but the possibilities in this direction are much greater than the attainments and the bulk of crude petroleum utilized yields few, if any, by-product values. The by-product accomplishments of the more progressive portion of the petroleum industry are shown in Fig. 89.

As crude petroleum advances in price and further attention is accorded chemical research, an enlarging by-product return may be counted on in the petroleum industry. Petroleum and coal-tar are the chief raw materials of synthetic organic chemistry, and the values hidden in these two substances, as already so well demonstrated in the case of coal-tar, can scarcely be overestimated.

CHAPTER XIV

NATURAL GAS AND NATURAL-GAS GASOLINE [1]

NATURAL gas occurs in intimate association with petroleum and independently in gas-pools in the proximity of oil deposits. This substance is accordingly commercially produced not only as a by-product of petroleum but separately as a distinctive undertaking. The bulk of the natural gas consumed in the United States is brought into use by large corporations operating as public utilities, but quantities of gas are also disposed of by oil-producing companies.

The magnitude of natural-gas service in the United States is not generally appreciated. Large sections of the country have long been partly to wholly dependent upon this ideal fuel. Domestic consumers number upward of 2½ million, and billions of cubic feet are annually employed for industrial heating and the generation of power. The consumption of natural gas in the United States in 1919 in comparison with the quantity of artificial city-gas used in that year is shown in Table 92.

TABLE 92.—CONSUMPTION OF NATURAL GAS COMPARED WITH THE UTILIZATION OF CITY-GAS IN THE UNITED STATES IN 1919

Data from U. S. Geological Survey and American Gas Association

(*In millions of M. cubic feet*)

City-gas:	
Carburetted water-gas	180
Coal-gas	65
Oil-gas	26
Surplus by-product gas *	51
Total	322
Natural gas	639

* Includes some gas made by other processes.

[1] It is impossible to discuss natural gas adequately without drawing upon the work if S. S. Wyer, who has done so much to elucidate the natural gas situation. For a detailed discussion of this subject, reference may be had to Wyer, Natural Gas: Its Production, Source, and Conservation, Bull. 102, Pt. 7, U. S. National Musuem, Smithsonian Institution, 1918.

Consumption of Natural Gas.—The actual production of natural gas in the United States is not known, since billions of cubic feet are wasted, used in the field, and otherwise unaccounted for. The quantity entering into consumption, however, is a matter of statistical record and is shown in Table 93 for the period 1915–1919. It will be observed that the bulk of the gas is employed for industrial purposes, the ratio of domestic consumption to total consumption being 35 per cent in 1915, 31 per cent in 1916, 32 per cent in 1917, and 38 per cent in 1918.

TABLE 93.—CONSUMPTION OF NATURAL GAS IN THE UNITED STATES BY YEARS, 1915–1919

Data from U. S. Geological Survey

	No. of Producers, Units of 1	Number of Consumers		Gas Consumed					
				Domestic		Industrial		Total	
		Domestic, Units of 1000	Industrial, Units of 1	Volume, Units of 1,000,000 M.	Average Price, Cents per M.	Volume, Units of 1,000,000 M.	Average Price, Cents, per M.	Volume, Units of 1,000,000 M.	Average Price, Cents per M.
1915	7205	2195	18,358	217	28.32	411	9.68	628	16.12
1916	7697	2362	18,278	235	28.63	518	10.21	753	15.96
1917	7573	2431	18,620	258	30.76	537	11.67	795	17.87
1918	7101	2509	16,581	271	31.35	450	15.23	721	21.29
1919*	.....	......	......	......	......	......	......	639	25.00

* Estimated.

The trend of the consumption of natural gas in the United States over the period 1906–1919, divided into its domestic and industrial components, is shown in Fig. 90. This chart indicates that the consumption of natural gas reached its maximum in 1917 and thereafter has shown a decline at approximately the same rate that characterized its previous increase. The diagram illustrates the fact, already too well known in all natural-gas consuming regions, that the annual output of this fuel has passed its maximum, and consumption is consequently suffering progressive curtailment. This outcome carries additional interest in that it presages what will inevitable overtake the petroleum resource. In the words of the Director of the U. S. Geological Survey: "Natural gas is a mine that is largely worked out; it has seen its best days and future dividends to the nation cannot equal those of the past."

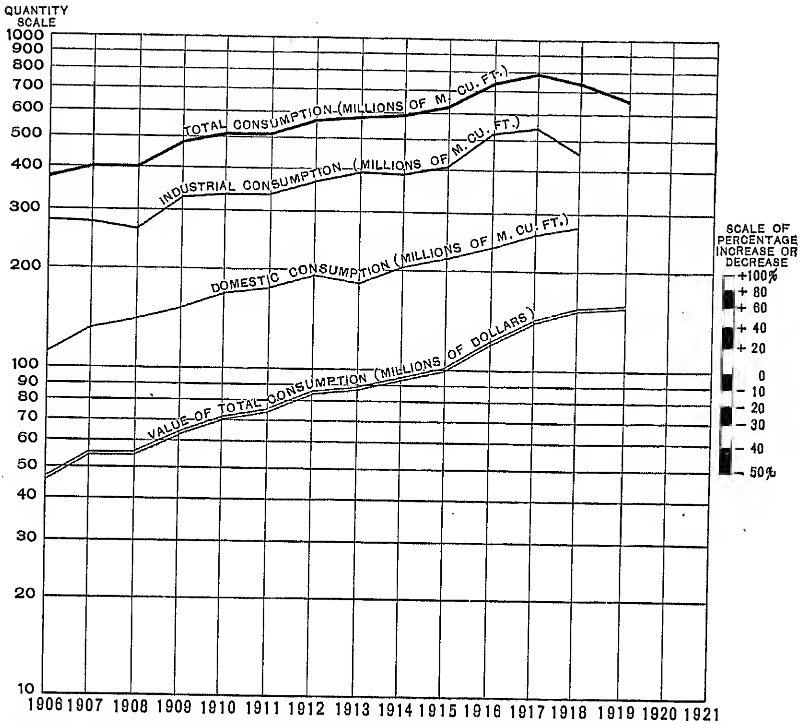


FIG. 90.—Trend of the production and value of the natural gas consumed in the United States by years, 1906–1919; data from U. S. Geological Survey.

TABLE 94.—ACREAGE CONTROLLED BY NATURAL-GAS PRODUCERS IN THE UNITED STATES IN 1918

Data from U. S. Geological Survey

(In thousands of acres)

	Natural-gas Acreage
In fee	1,081
Leased	12,343
Gas rights	1,154
Total	14,578

About 60 per cent of the total consumption of natural gas is utilized in the three states of Pennsylvania, Ohio, and West Virginia, where this product has not only given a cheap and convenient domestic service, but has also exerted a marked effect, now nearing its

close, upon the industrial opportunity afforded by those sections. The relative importance of the industrial and domestic rôle of natural gas in the leading gas-consuming states is shown graphically in Fig. 91.

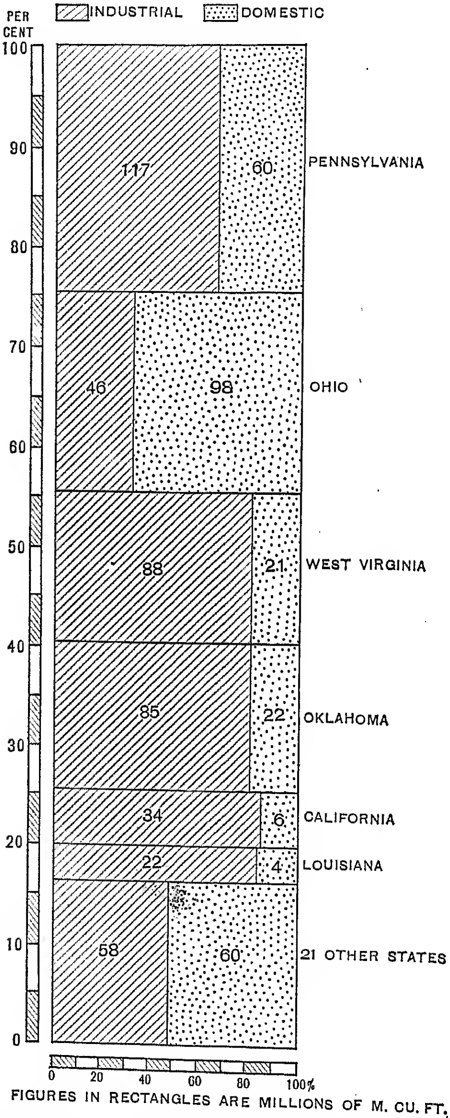


Fig. 91.—Relation of industrial and domestic consumption of natural gas in the United States in 1918.

Production of Natural Gas.—The production of natural gas, from an engineering standpoint, is quite similar to the production of petroleum, the two products in many instances being turned out jointly from the same well, although the bulk of the natural gas consumed is drawn from gas-wells in gas-fields. (See Fig. 92.)

The acreage controlled by natural-gas producers in the United States in 1918, is shown in Table 94.

The number of gas-wells and the extent of drilling activity in 1918 for natural gas compared with petroleum are shown in Table 95. A feature especially to be noted in Table 95 is the fact that in 1918, 7 per cent of the natural-gas wells were abandoned, whereas only 3 per cent of the petroleum wells ceased to be productive. The average life of natural-gas wells for the entire country is about 8 years; the average petroleum well is longer-lived.

TABLE 95.—WELL DATA FOR NATURAL GAS AND PETROLEUM IN THE UNITED STATES IN 1918

Data from U. S. Geological Survey

	Natural Gas				Petroleum
	Penn.	Ohio	W. Va.	Total U.S.	Total U. S.
Productive wells, Jan. 1, 1918.	14,534	5979	9329	39,283	197,149
Drilled in 1918:					
Gas	1,276	614	718	3,808	12,111*
Dry	258	297	170	1,508	3,135
Total	1,534	911	888	5,316	15,246
Abandoned in 1918	566	425	360	2,722	5,885
Productive, Dec. 31, 1918	15,244	6168	9687	40,369	203,375

* Oil-wells.

The effective production of natural gas, from hundreds of wells and widely scattered pools, is inherently a large-scale enterprise, involving a continuity of service from the field to the consumer. This aspect of the natural-gas industry is illustrated in Fig. 93 by a map of the properties, compressing stations and transmission lines of a large public-service corporation dealing in this product. The map is reproduced from a report by S. S. Wyer.

Natural gas occurs underground under a natural pressure termed its rock-pressure, and as the gas is produced the rock-pressure declines. The relationship of pressure to volume is definite, and in general a decline in rock-pressure of a given percentage means that the volume of gas in the underground reservoir has been reduced in like degree. A decline in rock-pressure, however, not only indicates that the ultimate supply is being depleted, but it also reduces the delivering capacity of the gas-well and thus results in a declining rate of output. Ultimately the rock-pressure falls below the point at which the gas will flow into the receiving lines and either the well must be abandoned or a compressor must be installed for increasing the pressure of the gas. The trend of the average rock-pressure of a pool or a field gives a basis for estimating the future life of the deposit. The average decline in rock-pressure, based on the performance of some 2500 wells in nearly all of the productive districts of Pennsylvania and New York, is shown in Fig. 94 for the period 1906–1919, with a projection ahead.[1] It appears from this chart that from 1906 to

[1] Data from W. Irwin Moyer, The Natural-gas Fields of Eastern United States and Their Probable Future Life, Nat. Gas Assoc. America, May, 1920.

1919 the average rock-pressure in West Virginia declined about 70 per cent and in Pennsylvania, about 65 per cent; and that at its

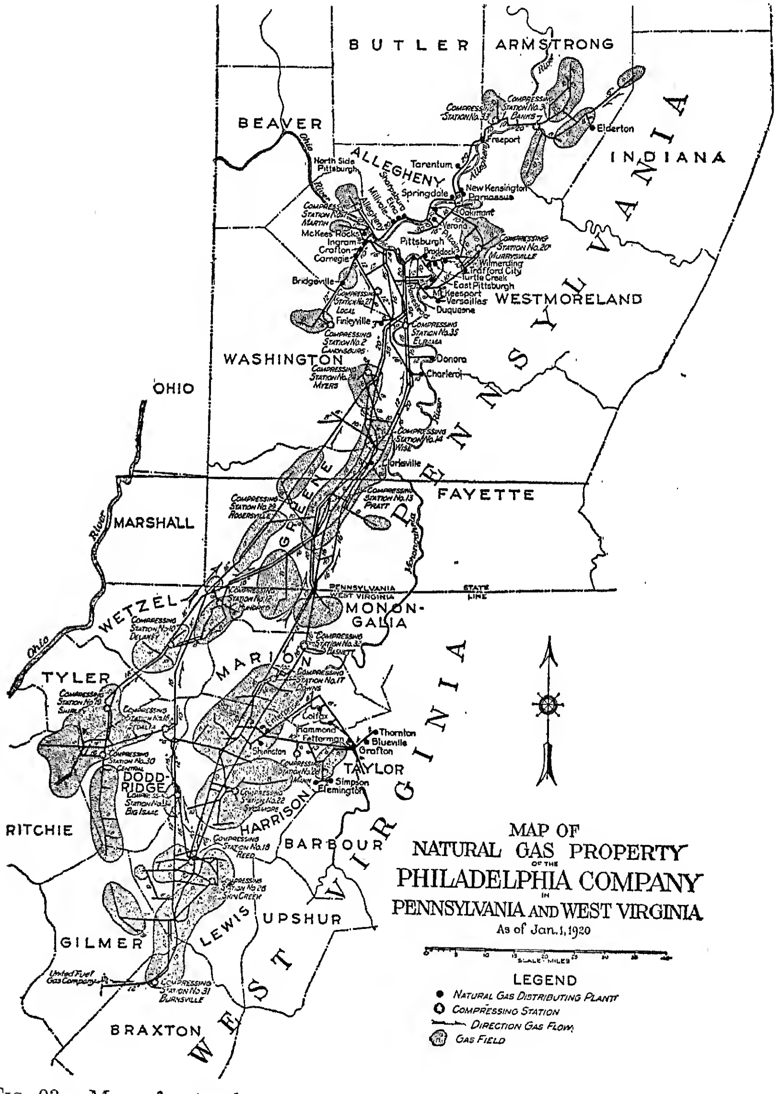


Fig. 93.—Map of natural gas property of the Philadelphia Company in Pennsylvania and West Virginia as of Jan. 1, 1920; after S. S. Wyer.

past rate of decline the pressure will reach 20 pounds in 1942 for West Virginia and 20 pounds in 1948 for Pennsylvania.

Transmission of Natural Gas.—The transportation of natural gas is an important step linking production with utilization. As with

petroleum, an extensive system of pipe-lines is employed for this purpose. The extent of the transmission system in the great natural-gas region of Pennsylvania, Ohio, West Virginia, and adjacent parts of New York, Maryland, Kentucky, and Indiana, is indicated by a map of this territory showing the towns dependent upon natural gas

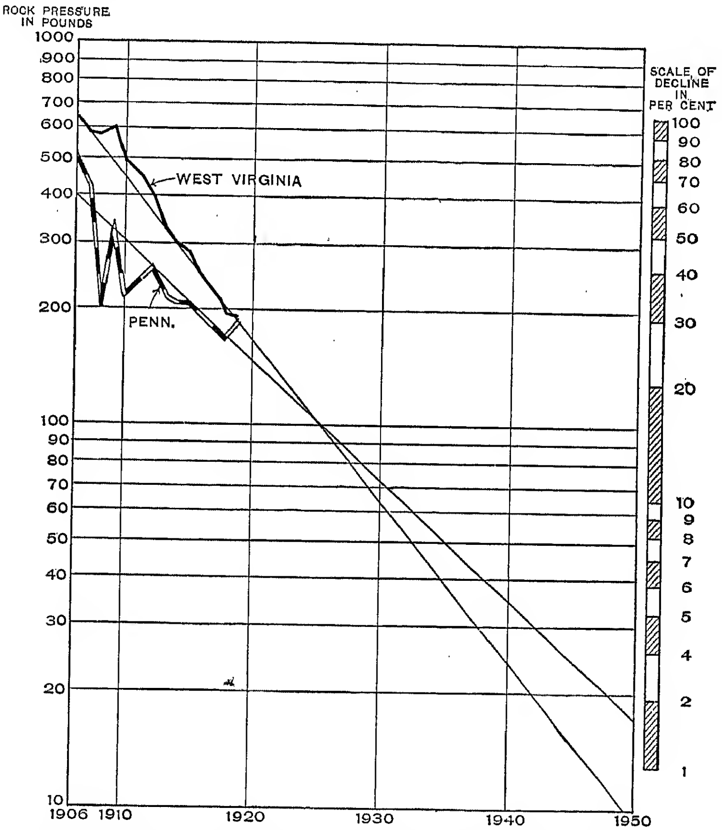


FIG. 94.—Typical rock pressure decline in natural gas fields of Pennsylvania and West Virginia, 1906–1919, with trend projected to 1950; data from W. I. Moyer, Nat. Gas Assoc. of America.

and the main transmission lines engaged in its distribution. (See Fig. 95.)

In order to expedite its transmission, the gas is compressed in stations along the line. Compression decreases the volume of the gas and increases its pressure. Gas is ordinarily raised to pressures of 200 to 400 pounds for transmission; and owing to the drop in pressure resulting from friction as the gas proceeds, recompression in successive stations becomes necessary. The gas travels at enor-

mous velocities in the mains, exceeding the speed of the fastest trains. As the rock-pressures of gas-wells decline, the capacity of the compressor station is lowered. A growing compressor installation is in consequence called for as the gas-fields age.

Utilization of Natural Gas.—The utilization of natural-gas is profoundly affected by a highly variable load factor which fluctuates with the season and also with the time of the day. The load factor varies more widely with domestic consumption than with industrial consumption, and natural-gas companies attempt to equalize the domestic load with industrial sales. The monthly domestic load of a typical natural-gas company is shown in Fig. 96, while the hourly load of a day in winter is given in Fig. 97.

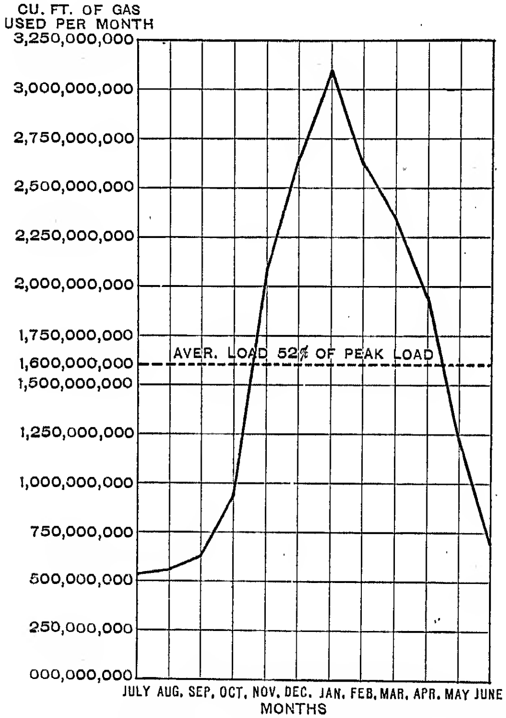


Fig. 96.—Typical monthly domestic load of a natural gas company; after S. S. Wyer.

As in the case of artificial gas, the appliances employed in the utilization of natural gas are extremely wasteful and little advance has been made in their efficiency in the past twenty years. The field of gas stands to-day in striking contrast to that of electricity, where constant effort in perfecting the appliance is responsible for much of the remarkable advance in the art that has taken place. With natural gas, the lack of progress on this score, attributable in part to the prevalence of such low prices for natural gas that the product was scarcely worth saving, is responsible for an unduly rapid and premature depletion of the resource.

Price of Natural Gas.—Natural gas possesses a heating-value nearly double that of the average grade of city-gas, yet the price of natural gas has averaged around one-fifth the price of city-gas on a

volume basis, or one-tenth the price on a B.t.u. basis. This discrepancy between the price of natural gas and its nearest analogue is highly significant; it indicates that natural gas has been exploited and sold on an uneconomic basis of opportunism; that the country has paid for its natural-gas service with a portion of the resource itself.

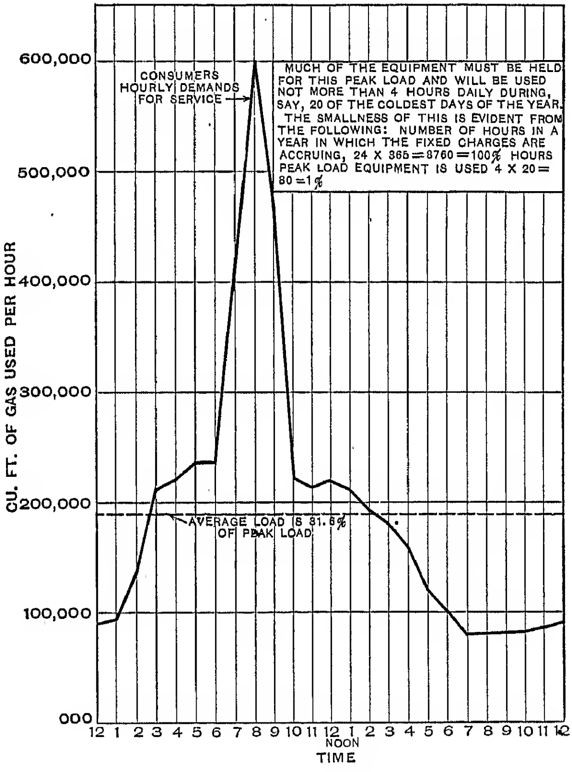


FIG. 97.—Typical hourly natural gas load in winter; after S. S. Wyer.

A comparison of the prices of several types of gas for a number of years is given in Table 96.

Wastes of Natural Gas.—It is difficult to describe without the use of superlatives the inefficient manner in which natural gas has been exploited in the United States. "Of all the pieces of extravagance of which the American people have been guilty, perhaps their reckless and wasteful use of natural gas is the most striking. . . ."[1] "The history of the natural-gas industry is an appalling record of almost

[1] Van Hise, The Conservation of Natural Resources in the United States, p. 60.

TABLE 96.—AVERAGE PRICE OF NATURAL GAS COMPARED WITH PRICE OF VARIOUS TYPES OF MANUFACTURED CITY-GAS

(Average price per M. cubic feet)

Year	Natural Gas			Coal-gas	Oil-gas and Water-gas
	Domestic	Industrial	All		
1915	$0.2832	$0.0968	$0.1612	$0.92	$0.90
1916	.2863	.1021	.1596	....	....
1917	.3076	.1787	.1787	.89	.86
1918	.3135	.1523	.2129	1.01	.90

unbelievable waste. The common methods of production, transmission, and use have resulted in wasting more gas than has ever been utilized."[1] "The annual reports of the conservation committee of the Natural Gas Association of America are stinging indictments of a criminal system, fostered by both the gas companies and the public, that has resulted in wasting more gas than has ever been utilized."[2]

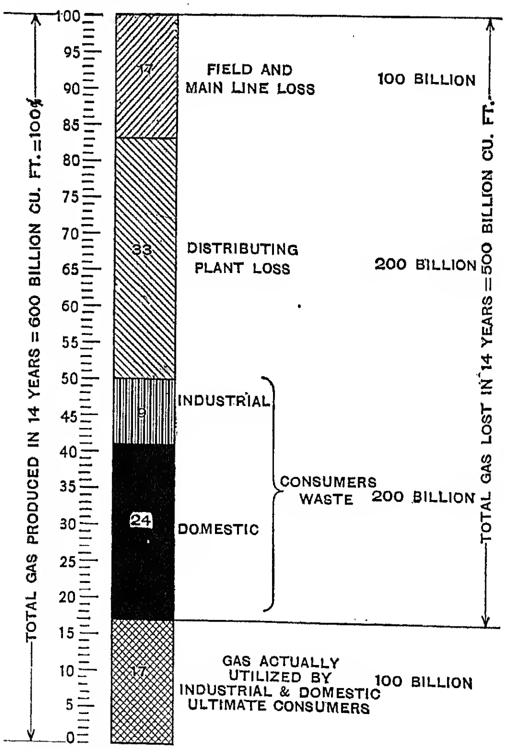


FIG. 98.—Analysis of the losses involved in the operations of a large gas company; after S. S. Wyer.

The losses of natural gas arise from excessive competition in drilling, hasty production, leakage in transmission, inefficient appliances, improper utilization, and many other causes.[3] Many of these con-

[1] Use and Conservation of Natural Gas, U. S. Fuel Administration.

[2] S. S. Wyer, Natural Gas: Its Production, Service and Conservation, U. S. National Museum, Bull. 102, Pt. 7, 1918, p. 51.

[3] See Wyer, loc. cit., pp. 52–66, for a detailed account of natural-gas wastes.

ditions are subject to correction and the life of the resource would be materially lengthened if the matter were accorded constructive economic and engineering treatment. An analysis of the operations of a large natural-gas company made by Wyer shows that of a total output of 600 billion cubic feet of gas in the course of fourteen years of operating history, only 17 per cent was actually utilized by the consumer (see Fig. 98). A view of the average waste of natural gas by the domestic consumer is given in Fig. 99; it is

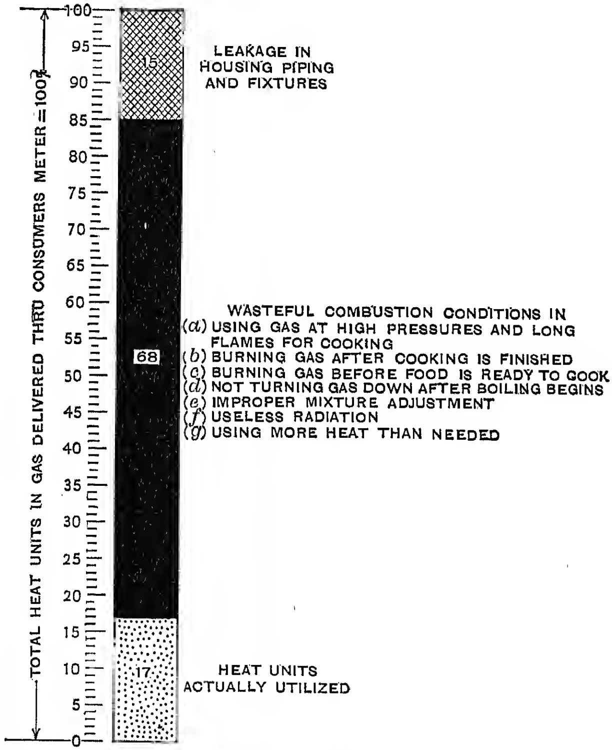


Fig. 99.—Analysis of average home wastes of natural gas; after S. S. Wyer, U. S. Bureau of Mines.

estimated by Wyer that the efficiency of most cooking and heating appliances could be trebled and the elimination of all preventable wastes in domestic consumption would " add fifteen to twenty years to the period that natural gas will be available for domestic use."[1]

Conservation of Natural Gas.—There is critical need for increasing the service value of the declining supply of natural gas by eliminating preventable losses in its production and transmission, and by

[1] Technical Paper 257, U. S. Bureau of Mines, p. 21.

increasing the efficiency of its utilization. As pointed out by Wyer:[1]

> "The natural-gas industry is in a transition stage, going from the large volume and low-priced basis of the past to the small volume and inevitable higher price of the future. Strong individualism dominated the past. Public policy will ultimately require that legalized and regulated collective co-operation, rather than cut-throat competition, dominate the future. The greatest need of the industry to-day is the adequate recognition of the dominating factors in the natural-gas problem, which are:
>
> 1. Mandatory pooling of field operations coupled with an adequate market price.
> 2. Education of the natural-gas producers, and of the public, coupled with national constructive legislation."

Other more specific measures advocated by Wyer[2] include: Removal of all gasoline suspended in the gas; the intensive and extensive use of compressors in order to extract a larger percentage of the gas from the ground; careful measurement of the gas produced, in the field, into and out of transmission lines, and into distributing plants, in order to have a constant check on the leakage; attention to the disintegrating action of stray electric currents, upon the gas mains; development of lower distributing pressures; more efficient utilization, through proper adjustment of old appliances and construction of more efficient appliances; and the placement of natural gas upon a price-level adequate to insure efficient development, discourage improper industrial consumption, and in general render this product worth saving.

The steps likely to be taken from now on toward insuring a fuller utilization of natural gas than has characterized the past will carry additional interest as forecasting the measures that may later come to be applied to petroleum.

Carbon Black from Natural Gas.[3] Carbon black is an amorphous form of soft carbon made by the incomplete combustion of natural gas. Fifty-two million pounds were produced in the United States in 1919, having an average value of 7.3 cents a pound. In its manufacture, 50 billion cubic feet of natural gas was used, nearly 8 per cent of the country's entire consumption of natural gas in that year, and the yield was approximately 1 pound of carbon black from each M cubic feet of gas. The carbon black industry establishes itself

[1] U. S. National Museum, Bull. 102, Pt. 7, 1918, pp. 62–63.

[2] Present and Prospective Supply of Natural Gas Available in Pennsylvania, 1918, pp. 68–69.

[3] See E. G. Sievers, Carbon Black Produced from Natural Gas in the United States in 1919, U. S. Geological Survey, May, 1921.

in the vicinity of cheap natural gas. The distribution of the industry is shown in Table 97.

TABLE 97.—PRODUCTION OF CARBON BLACK IN THE UNITED STATES IN 1919, BY STATES

Data from U. S. Geological Survey

States	No. of Plants	Carbon Black Produced		Natural Gas Consumed	
		Millions of Pounds	Average Price, Cents per Pound	Millions of M. Cubic Feet	Average Yield per M. Cubic Feet, in Pounds
West Virginia	23	29.9	7.8	23.1	1.3
Louisiana	7	14.0	6.6	20.3	0.7
Wyoming, Montana	2	4.87	4.7	4.31	1.1
Oklahoma, Kentucky	2	2.92	8.3	1.95	1.4
Pennsylvania	2	0.32	15.0	0.23	1.3
Total	36	52.1	7.3	49.9	1.04

About 45 per cent of the output is used in the rubber industry as a tire filler; 25 per cent is employed in the manufacture of printing ink adapted to fast press work; 17 per cent is exported; and 10 per cent is used in making stove polish. From the point of view of conservation, the manufacture of carbon black is a constructive enterprise only where the gas, already under production, enjoys no domestic or industrial market. Vast quantities of natural gas have been improperly utilized in the manufacture of this product.

Gasoline from Natural Gas.[1]—Natural gas consists of a mechanical mixture of permanent gases and condensable vapors; the condensable constituents are water vapor and gasoline vapor. The gasoline vapor may be condensed and recovered in liquid form, and in recent years natural gas has become a substantial source of commercial gasoline. Natural gas from gas-wells is leaner in gasoline vapor than the gas produced from oil-wells; natural gas lean in gasoline vapor is termed dry gas, while a product richer in gasoline vapor is called wet gas.[2] The natural gas that flows from oil-wells coming out between the casing and the tubing is frequently termed

[1] For detailed statistical data on this subject, see E. G. Sievers, Natural-gas Gasoline in 1919, U. S. Geological Survey, 1921.

[2] These terms have reference also to the content of water vapor.

casing-head gas, and the gasoline made from this gas is called casing-head gasoline. In the Mid-Continent region, the industry manufacturing gasoline from natural gas is spoken of as the casing-head gasoline industry, a name changed by the trade in 1921 to the natural gasoline industry.

The growth in output of natural-gas gasoline in the United States has been notably rapid, as shown in Fig. 100. It will be observed that the output of this type of gasoline is rapidly approaching a limiting factor, the total quantity of natural gas consumed; and that the yield per unit of natural gas treated is declining, as indicated by the crossing of curves *B* and *C* in Fig. 100. Statistical data showing the growth of the natural-gas gasoline industry are presented in Table 98.

TABLE 98.—GROWTH OF THE NATURAL-GAS GASOLINE INDUSTRY IN THE UNITED STATES

Data from U. S. Geological Survey

Year	Gasoline Produced in United States Millions of Gallons	Total Gasoline Produced from Natural Gas, Millions of Gallons	Natural Gas Treated, Millions of M. Cubic Feet	Average Gasoline Yield per M. Cubic Feet Gas, Gallons	Number of Plants	Daily Capacity of Plants, Thousands of Gallons
1911	....	7.43	2.48	3.00	176	37.1
1912	....	12.1	4.68	2.6	250	61.3
1913	....	24.1	9.89	2.43	341	152
1914	....	42.7	16.9	2.43	386	179
1915	....	65.3	24.1	2.57	414	232
1916	2059	103	209	0.496	596	495
1917	2851	218	429	0.508	886	902
1918	3570	283	449	0.63	1004	1022*
1919	3958	352	480	0.74	1191	......

* Estimated.

The marked increase in output that characterized 1916 should not escape attention. This sudden expansion came as a result of the recovery of the gasoline market from the depressing effect of the Cushing overproduction.

Gasoline is recovered from natural gas chiefly by two methods, the compression method and the absorption method. Before 1916, the output was obtained almost exclusively by the compression method from wet gas flowing from oil wells. From 1916 on, the absorption method has come into growing importance, extending the commercial extraction of gasoline to the so-called dry gas, too

lean in gasoline content to warrant treatment by compression methods. The relative contributions made by the two processes for the period 1916–1919 are shown in Table 99.

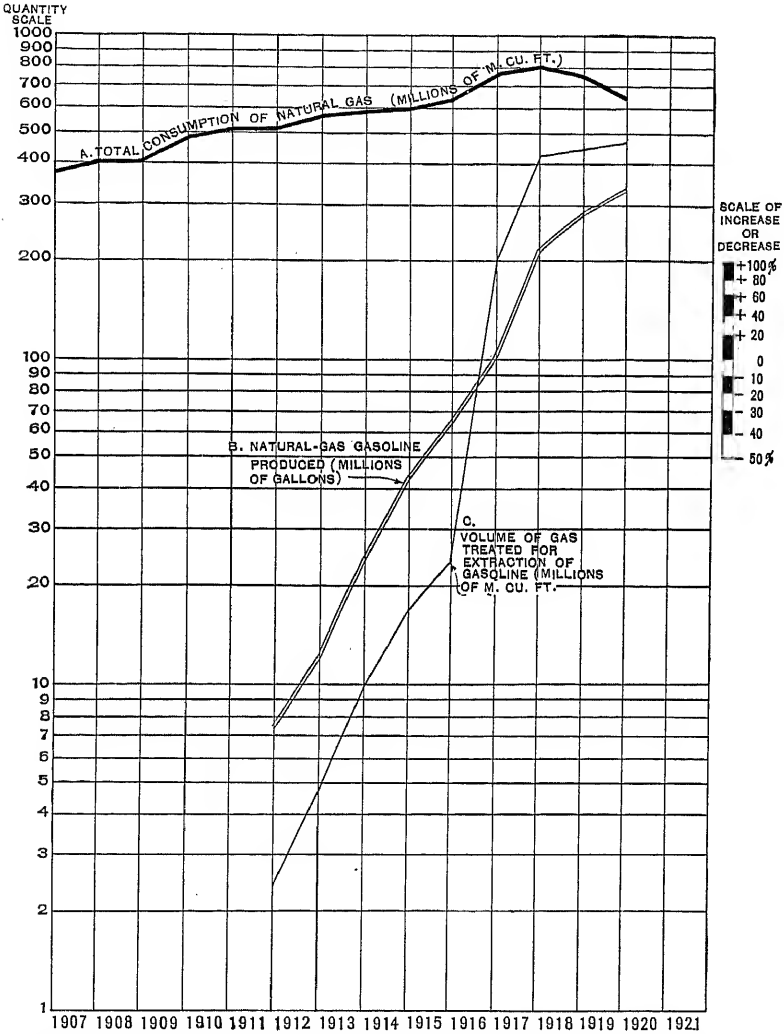


FIG. 100.—Trend of the production of natural-gas gasoline in the United States compared with consumption of natural gas, by years, 1911–1919; data from U. S. Geological Survey.

In 1919 over half of the natural-gas gasoline was produced in Oklahoma; West Virginia, California, and Pennsylvania ranking next in order. The relative importance of the various states as contributors during the period 1911–1918 is shown in Fig. 101.

TABLE 99.—OUTPUT OF NATURAL-GAS GASOLINE IN THE UNITED STATES, 1916–1919, BY METHODS OF PRODUCTION

Data from U. S. Geological Survey

Year	By Compression *				By Absorption			
	No. of Plants	Gasoline Produced, Millions of Gallons	Gas Treated, Millions of M. Cubic Feet	Average Yield per M. Cubic Feet Gas, Gallons	No. of Plants	Gasoline Produced, Millions of Gallons	Gas Treated, Millions of M. Cubic Feet	Average Yield per M. Cubic Feet Gas, Gallons
1916	550	85	36.7	....	46	18.6	172	....
1917	784	169	79.5	2.123	102	49.0	350	0.140
1918	865	220	99.9	2.20	139	62.8	349	0.18
1919	1025	261	117.7	2.21	166	90.4	375	0.24

* Includes some production by vacuum pumps.

The average price per gallon for natural-gas gasoline for a number of selected states and the country as a whole is given in Table 100.

TABLE 100.—AVERAGE PRICE OF NATURAL-GAS GASOLINE IN THE UNITED STATES, 1911–1919

Data from U. S. Geological Survey

(In cents per gallon)

Year	Oklahoma	West Virginia	California	Pennsylvania	Whole Country
1911	5.40	7.18	.....	7.47	7.16
1912	6.3	9.6	10.8	10.6	9.6
1913	8.94	10.54	10.87	11.01	10.22
1914	6.44	7.45	8.36	7.79	7.28
1915	7.46	8.54	7.60	9.66	7.88
1916	12.13	16.12	13.37	17.77	13.85
1917	18.71	19.93	15.40	20.01	18.45
1918	17.3	19.9	15.5	20.6	17.8
1919	17.1	23.3	14.2	21.7	18.2

Natural-gas gasoline is a highly volatile product, with a relatively low initial point and end-point. It vaporizes too readily to be used in its raw condition and, having the capacity to contribute to less volatile petroleum distillates the qualities requisite in motor-fuel, it is employed for blending with kerosene, naphtha, or straight-run gasoline of relatively high end-point. This product, therefore, is responsible for the output of something like twice the quantity of commercial gasoline represented by its own volume. By virtue of its low-boiling constituents, natural-gas gasoline contributes volatile

components that permit easier starting of the engine and give greater operating flexibility when properly blended. In times of strong demand, however, natural-gas gasoline is frequently employed

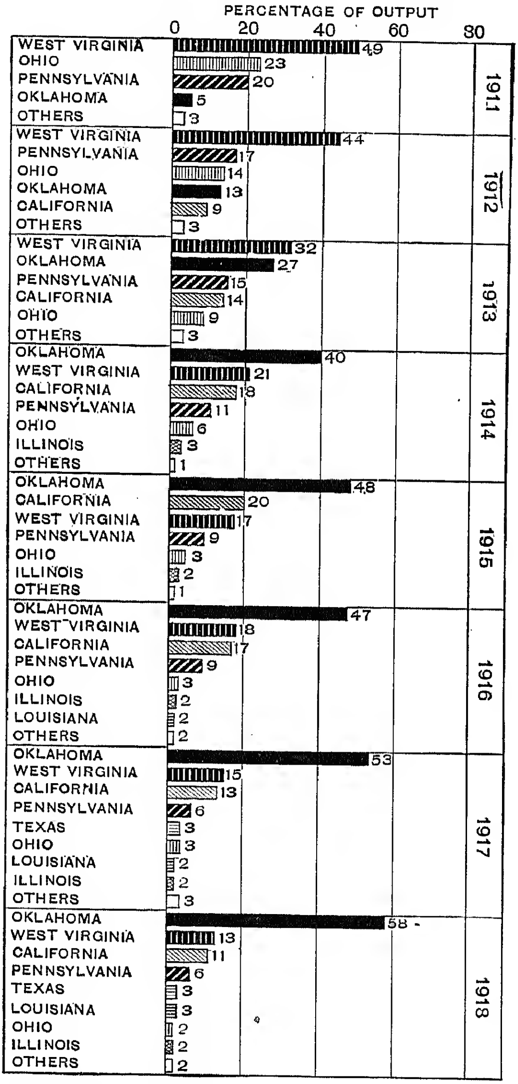


FIG. 101.—Rank of states producing natural-gas gasoline, 1911–1918, in percentages of each year's output; after E. G. Sievers, U. S. Geological Survey.

blended with heavy distillates with less satisfactory results. The development of natural-gas gasoline has encouraged the upward trend in the end-point of commercial gasoline and hence exerted a far-reaching effect upon the supply of motor-fuel.

CHAPTER XV

MARKETING OF PETROLEUM PRODUCTS

An outstanding characteristic of the petroleum industry is the high degree of proficiency attained in the distribution and marketing of its products. The crude oil is carried by pipe-line or tank-steamer to refineries in proximity to demand, whence the refined products are distributed in tank-cars to the consuming centers and from there in tank wagons to the points of consumption. This vast and extensive machinery of distribution is for the most part operated by the industry itself as an integral part of its manufacturing activities.

The petroleum interests have paid unremitting attention to the means for extending the markets for petroleum products. The incentive for this attention has been ever present in the form of a production of crude oil that grew more rapidly than the normal industrial development of the country. A lavish supply of petroleum was continuously forthcoming under the impetus of the highly competitive, individualistic methods of production in vogue, and exerted a constant pressure in the direction of forcing an adequate outlet for the products involved. In consequence, the efforts to adapt this raw material to industrial and social needs came to be highly organized, while the production of the raw material itself found sufficient stimulus in the undirected energy of the wildcatter and the ready productivity of the resource. To-day, therefore, we find the marketing of oil, with its preparatory steps of transportation and refining, to be a closely integrated enterprise, handling tremendous volumes of products, through diverging and ramifying channels of distribution of a unique and singularly efficient character.

In contrast to the oil industry, which has thus far focussed its main efforts upon the distribution of its products, with efficiency in production under neglect, stands the automotive industry. This great activity came upon the scene with a large potential demand ready to be filled; the problem here was not marketing, but production. In consequence, the automotive industry developed with every effort bent upon quantity production, in an attempt to satu-

rate the demand with the greatest possible dispatch; the matter of placing the product was relatively simple. Accordingly the automotive industry stands to-day as an activity whose effectiveness in production is carried to a high degree of attainment, with marketing a wholly subordinate issue; while the oil industry enjoys an effectiveness in marketing that is scarcely to be found elsewhere in the entire industrial field with production disorganized and wasteful.

The contrast is significant. The automotive void is rapidly becoming filled; while the demands for the products of petroleum have been encouraged to an insistence that cannot continue to be fully met from the resources in sight. The relative focus of the two industries may soon be expected to change. The automotive industry, with little further advance possible in production efficiency, will turn its attention to marketing its product against a gathering sales resistance; while the oil industry from now on will find its chief problem in gaining efficiency in production in order to more adequately meet the demands which will mount apace without direct attention.

Development of Oil-marketing.—In order to gain a proper perspective of the developments in the marketing of mineral oils, it is necessary to review briefly the recent history of the industry. We have already noted that the production of crude petroleum has grown mainly on the basis of individual enterprise in the drilling and operation of wells under highly competitive conditions, while the activities having to do with transportation, refining and marketing have tended toward integration under the direction of large-unit, corporate enterprise.

At the end of the first decade of the present century, a minor part of the output of petroleum products came from a large number of independent companies, and the remainder from the Standard Oil Company of New Jersey, which operated throughout the United States as a single unit and under the supervision of one executive.[1] The marketing of petroleum products was then carried on by the Standard Oil Company, by the Independent Companies affiliated with refining, and by oil jobbers who bought directly from the independent refiners.

In 1911, after long and sensational litigation, the Standard Oil Company of New Jersey was dissolved by judgment of the Supreme Court, and the original organization broken up into thirty-three

[1] For a detailed discussion of marketing practices, consult A. G. McGuire, Prices and Marketing Practices Covering the Distribution of Gasoline and Kerosene throughout the United States, U. S. Fuel Administration, 1919.

separate and independent units, occupying territories with geographic rather than commercial boundaries and requiring for each unit a separate and independent administration.

The result of the dissolution decree upon the marketing of petroleum products is described as follows by the U. S. Fuel Administration:

> One of the immediate and permanent results of the application of this principle was to limit the interest of the executives of the new commercial entities to market values in the territory in which they operated. The factor which had worked to exert national rather than sectional influence upon the trend of the markets and to establish a general level of prices for petroleum products, subject only to transportation and similar normal variations, had been wiped out of existence. The fragments which had formerly constituted the Standard Oil Co. (New Jersey) were then found, in their new corporate form, to be unable separately to perform the service to the public which had been accomplished by the complete organization. Many of the units were without the equipment both to manufacture and distribute petroleum products in the territory in which they operated at the time of the court decree. Some of them, formerly merely marketing subsidiaries of the original corporation, were now faced with the necessity of finding new sources of supply. The corollary to this was that those units which in the general scheme had been devoted principally to the refining of oil found that new markets for their output were the first essential to their existence.
>
> It is no reflection upon the high purpose and public zeal which brought about the attempt at Government control to say that experience has shown that action to be an economic mistake and that the new order which it established accentuated rather than retarded the conditions which it was designed to correct. This development has not been the outcome of lax or unintelligent enforcement of the dissolution order, for the weight of evidence accumulated as the result of keen and almost constant surveillance by several departments of the Government is entirely in support of the conclusion that the dissolution decree has been scrupulously observed.
>
> The separate units do not compete, but, in general, limit their activities to the territory in which they were operating at the time of the decree in the Standard Oil case. The active competition of two or more of them for business in the same territory would have much the same effect on outside competitors as a combination between them to suppress competition, and might well create the suspicion that this was the purpose. By not invading each other's territory they perhaps follow the only practical course to avoid charges of collusion and of attempts to evade the decree in the dissolution suit. These units trade with each other in conformity with the law, but after eight years the dissolution decree has been found neither to have destroyed nor lessened the influence of the so-called Standard Oil companies in their respective territory. It has simply proved that legislation can not change the operation of economic laws.
>
> The admitted efficiency which characterized the original corpora-

tion was not removed by the dissolution decree and is still in evidence in the detached organizations. The advantage of large cash reserves, the possession of strategic commercial locations, the experience gained from acquaintance with the industry virtually since its inception, have all contributed to maintain the position of this particular group and to continue its influence upon markets and prices. After eight years of operation under the dissolution decree, the premier position and influence of the Standard Oil group remains unquestioned. The present situation conclusively demonstrates that legislation can not change the working out of fundamental economic principles.

Marketing of Gasoline.—Gasoline is marketed by the so-called Standard Companies, by the Independents, and by jobbers.[1] Roughly two-thirds of the gasoline distributed in the United States is marketed by the Standard Companies which purchase part of this quantity from the independent refiners, since the former group refines only about one-half of the oil run to stills in this country.

The Standard group has developed a highly perfected system of distribution involving the direct placement of the product in the hands of the consumer through the medium of service stations, tank-wagon delivery, and tank-stations in sparsely settled districts. Every step in the movement of the product from the refinery to the ultimate consumer has been worked out with the utmost regard to economy and efficiency, and the distribution of gasoline stands almost without a rival in the commercial field.

The large independent refineries market much of their gasoline through service stations and tank-wagon delivery; but, as the development of the requisite marketing organization and equipment is a large-scale enterprise demanding extensive investment, the smaller independents, as well as the larger ones in part, sell their product to the Standard Companies, and to jobbing organizations operating independently in localized territories. The jobber, indeed, is somewhat complementary to the small skimming plant; and hence jobbing is most active in the Middle West, where the products of the small refinery are available in greatest abundance.

Before the Standard Oil combination was dissolved in 1911, the whole area of the United States was divided among its eleven marketing companies, and each one operated almost exclusively in its assigned field. After the dissolution, the existing marketing arrangements by which there was this division of territory remained undisturbed, and accordingly the various Standard companies to-day

[1] It is common practice in the trade to designate the companies formerly combined in the Standard Oil Company of New Jersey as the Standard group, and all other companies as the Independents.

operate separately in the original territories without substantial change. The location and extent of these marketing territories are shown in Fig. 102. The Standard companies take the lead in determining the sale price of gasoline by announcing the price at which this product may be purchased from the tank-wagon. The retail price at service stations is usually 2 cents higher than the tank-wagon price. The other marketing companies and the jobbers in any given territory usually adjust their prices in accordance with the tank-wagon price as determined by the Standard companies. The tank-wagon price, in turn, tends to fluctuate in sympathy with the price of crude petroleum and with the price of the products made jointly with gasoline from this raw material. "Price initiative to-day seems to be left generally to the Standard companies and competition is apparently more directed to developing facilities for getting business than to seeking to obtain it by underselling."[1]

Occasionally, where there is an abundant supply of gasoline, the independent marketers and jobbers in a given locality may begin to sell under the prevailing tank-wagon price. Usually, in such instances, a price-cutting war develops, and the price of gasoline is forced down below a profitable level. Of late years, the jobbing interests have sought to avoid the precipitation of this type of cut-throat competition, but a revival in the tendency was apparent in 1921.

Mainly as a result of the dissolution of the original Standard Oil Company into separate activities, occupying distinctive and non-overlapping territories, the gasoline market has in some degree become sectionalized, with minor divergences and inconsistencies in marketing practices and price from locality to locality. It thus comes about that two adjacent points on opposite sides of a state line may see a difference of as much as 2 or more cents in the price of gasoline. For example on January 1, 1921, the tank-wagon price of gasoline in New York, served by the Standard Oil Company of New York, was 31 cents; whereas the tank-wagon price of gasoline in Newark, N. J., served by the Standard Oil Company of New Jersey was 28.5 cents a gallon. This sort of divergence in price has given rise to much misunderstanding and criticism, but could scarcely be altogether avoided under the circumstances surrounding the marketing of this product without an undue duplication of marketing agencies.

The division of territory amongst the companies of the Standard group has also given rise to divergencies in marketing practice in dif-

[1] The Advance in Price of Petroleum Products, Federal Trade Commission, Washington, 1920, p. 53.

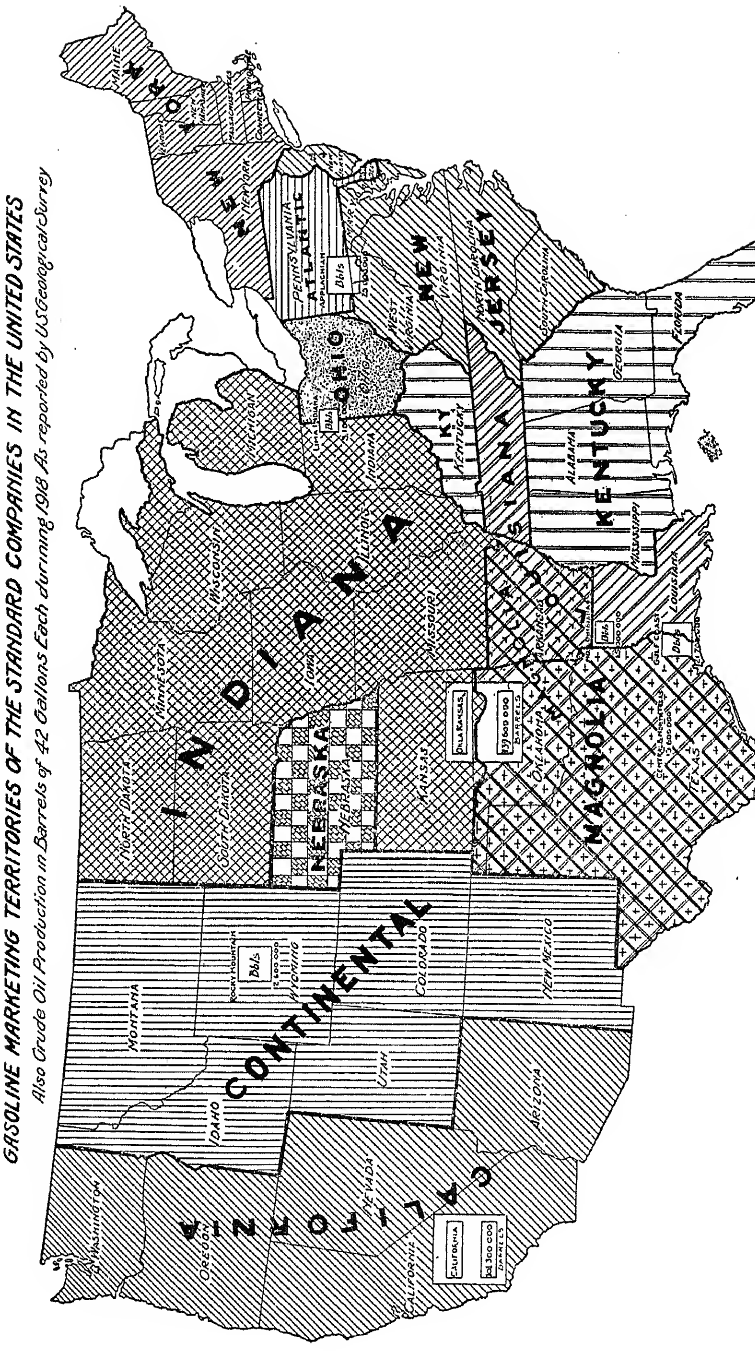


Fig. 102.—Gasoline marketing territories of the Standard Companies in the United States.

TABLE 101.—MARKETING PRACTICE OF THE STANDARD OIL COMPANIES IN VARIOUS STATES IN 1918

(After A. G. Maguire, U. S. Fuel Administration)

Name of Standard Oil Co.	Operating in—	Retail Service Stations	Price	Remarks
Standard Oil Co. of New York	New York, Connecticut, Massachusetts, Vermont, New Hampshire, Rhode Island, and Maine	None...	Single	
Atlantic Refining Co.	Pennsylvania and Delaware	Many..	10 per cent off retail for resale	Also 10 per cent off retail for large consumers taking direct from tank-wagon
Standard Oil Co. (New Jersey)	Maryland, Virginia, West Virginia, District of Columbia, North Carolina, and South Carolina	None...	Wholesale price for resale 1 cent per gallon extra to the consumer	
Do............	New Jersey.......	..do....	Single...........	One price in New Jersey on account of State law
Standard Oil Co. of Ohio	Ohio............	Great many	Resale 1 cent under retail price. Otherwise retail price applies	
Standard Oil Co. of Kentucky	Kentucky, Mississippi, Alabama, Florida, and Georgia	Few....	General tank-wagon price 2 cents off for resale	Service stations sell gasoline at tank-wagon price
Standard Oil Co. of Louisiana	Louisiana, Arkansas, and Tennessee	Many..	Single	
Magnolia Petroleum Co.	Texas, Oklahoma, and Arkansas	..do....	Resale 2 cents under tank-wagon price	
Standard Oil Co. of Indiana	Illinois, Indiana, Michigan, Wisconsin, Missouri, Iowa, Minnesota, North Dakota, South Dakota, Kansas and few stations in Oklahoma	Great number	Single	
Standard Oil Co. of Nebraska	Nebraska.........	Few....	....do	
Continental Oil Co..	Colorado, Utah, New Mexico, Wyoming, Montana, and Idaho	..do....	Wholesale except at service stations where 2 cents extra charged	
Standard Oil Co. of California	California, Arizona, Nevada, Oregon, and Washington	Many..	2 cents less when for resale	

ferent parts of the country, as shown in Table 101, reflecting the conditions prevailing in 1918, which have not changed substantially since that time.

Marketing of Kerosene.—Kerosene is marketed in much the same manner as gasoline; only the service station is unimportant, and the major part is distributed to the consumer through the agency of the tank-wagon and tank-station; considerable use is also made of the retail store. The price of kerosene is usually determined in the same manner as the price of gasoline; the tank-wagon price charged by the Standard companies being followed by the other marketers. There is a systematic differential between the price of the two products, and the two prices tend to fluctuate in unison. Of recent years, however, the differential has been narrowing since the price of kerosene has advanced the more rapidly of the two.

The export trade in kerosene is large and the marketing of kerosene abroad has received careful attention. To-day American kerosene reaches literally to the four corners of the globe, since markets nearer at hand were inadequate to afford outlet to the supply of this commodity. The five-gallon kerosene can is a familiar object in the most out-of-the-way regions.

Marketing of Fuel Oil.—The distribution of fuel oil is entirely different from that of gasoline or kerosene. Consumed in bulk by industrial establishments, railroads, and steamships, its placement does not require the attenuated distribution demanded by gasoline and kerosene. It is sold for the most part under direct consignment from the refinery to the consumer and much of the supply is contracted for in advance. Its market price in the past has tended to fluctuate widely under varying conditions of supply and demand, especially as a result of the tendency of crude petroleum to display a periodic acceleration in advance of demand, and consequently the need for anticipating conditions has been particularly important in order to secure advantageous disposition.

The storage capacity demanded by fuel oil has rendered the matter of marketing especially difficult for the small refiner, who must keep this product continuously on the move to make room for the new output. In consequence, the small refiner is unable to maneuver with the purpose of taking advantage of market conditions. On the contrary, it frequently happens that an appearance of oversupply is created entirely fortuitously by a coincidence of accumulating storage in adjacent refineries, to the entire demoralization of the local market.

Marketing of Lubricating Oils.—Lubricants present a third type of problem in marketing. These products are highly fabricated into

a diversity of types to meet a wide range of specialized demands. They are not bulk products in the sense that gasoline or fuel oil are, but require individual treatment in their placement into use.

The motor-oils, which now constitute a substantial portion of the entire output of lubricants, are in part handled like gasoline through service stations and by tank-wagons to garages and stores.

Lubricating oils designed for industrial service are usually sold directly on contract to the industrial establishments. The selling of such oils customarily involves an engineering service to fit the oil to the functions it is designed to perform. Lubricating sales are consequently often handled by an engineering, or semi-engineering, staff; some companies employ lubricating engineers who work in conjunction with the salesmen.

A considerable volume of lubricating oils is handled by jobbing interests, some of whom buy the base oils and compound them into special grades bearing the jobber's name. This tendency, together with the competition prevailing amongst the refiners, has resulted in a confusing multiplicity of brands and an extensive range of advertising and other specialized sales effort.

Inspection Laws.—In the early days of oil-marketing, the various states passed oil inspection laws with direct reference to the flash point of kerosene, in order to safeguard the users of this product from explosions. Very little attention was devoted to gasoline beyond a requirement that it should be retailed in marked containers and labeled "dangerous." With the growth of automotive transportation, however, the conditions of a few years ago have been reversed and there is no tendency for any gasoline to be left in the kerosene to lower its flash point; hence the basis of the kerosene inspection laws is obsolete.

A number of states and a few cities have tried to regulate the quality of gasoline, but most of such requirements are unreasonable and unscientific, and their enforcement would materially reduce the output of gasoline. "Most of the laws have obviously been drafted by people lacking even an elementary knowledge of the methods of producing and analyzing gasoline." The U. S. Fuel Administration made a canvass of the state regulations and found them to be wholly impracticable and in some instances ridiculous. Since then a Federal committee on the standardization of petroleum has worked on the matter and with the Bureau of Mines has succeeded in bringing some degree of consistency into the situation. Unscientific and obsolete requirements have proved a troublesome and costly handicap to the marketing of petroleum products.

Market Analysis.—Of recent years, many of the marketing companies have devoted considerable attention to the measurement of the size and geographic disposition of the various demands for petroleum products, in order to eliminate waste effort in distribution and salesmanship. Service stations are usually located on the basis of a count of automobiles that pass. The expansion of marketing equipment has proceeded, in part, upon the exact measurement of the consumptive requirements of the territory to be served. And wide use has been made of the registration figures for automobiles and trucks, in order to determine the rapidly expanding requirements for gasoline and motor-oil. A well-advised marketing company should know the exact distribution of automotive equipment and manufacturing activity in its area of operations.

CHAPTER XVI

ANALYSIS OF THE EXPORTS OF PETROLEUM PRODUCTS

Introduction.—Exports of mineral oils from the United States constitute one of the leading commodity classes entering into foreign trade and represent an important fraction of the petroleum products refined in this country. In 1920 the value of the exports of mineral oils was 6.8 per cent of the total value of all exports, while in 1919 the proportion was 4.4 per cent and in 1918, 5.7 per cent. The only groups of commodities that bulked larger in the 1920 export returns were cotton and breadstuffs, each representing about twice the value of the mineral oils sent abroad. (See Fig. 103.)

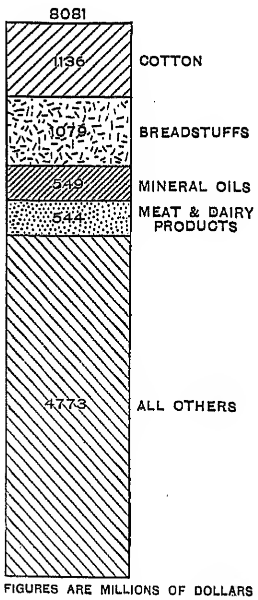


Fig. 103.—Value of the exports of mineral oils compared with other exports from the United States in 1920.

Exports of mineral oils are confined largely to the four major petroleum products—gasoline, kerosene, fuel oil, and lubricating oils—the relative volume of crude petroleum exported being small. Thus, of the total mineral oils shipped abroad in 1920, only 10.9 per cent in quantity and 5.3 per cent in value represented crude petroleum. Compared with domestic production, exports of crude petroleum in 1920 amounted to 1.8 per cent, while exports of petroleum products represented 16.1 per cent.

Ratio of Exports to Domestic Production.—The American petroleum industry turns out a nearly 20 per cent greater volume of petroleum products than is necessary to meet domestic requirements, the surplus being sold abroad under the heading of exports. Fig. 104 shows in graphic form the proportions of the domestic output of gasoline, kerosene, fuel oil, and lubricating oils which went into foreign trade in 1920. It will be observed at once that the propor-

tions of kerosene and lubricating oils exported are much higher than the proportions of gasoline and fuel oil.

The ratio of exports to domestic production over the past few years for the leading petroleum products is shown in the table following:

TABLE 102.—RATIO OF EXPORTS TO DOMESTIC PRODUCTION FOR THE LEADING PETROLEUM PRODUCTS, 1914–1920

Year	Gasoline and Naphtha, Per Cent	Kerosene, Per Cent	Fuel Oil, Per Cent	Lubricating Oils, Per Cent
1914	14.0	52.1	18.8	37.2
1916	17.4	58.8	20.6	41.8
1917	14.6	38.1	17.3	37.2
1918	15.6	26.9	16.4	30.6
1919	9.4	41.7	8.1	32.5
1920	13.0	37.2	9.6	39.2

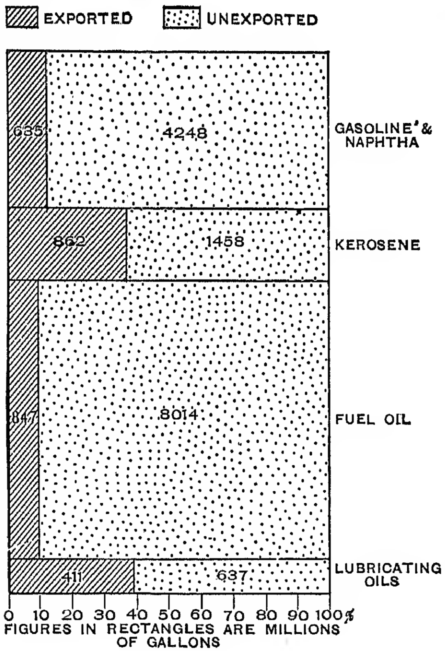


FIG. 104.—Relation of the volume of the leading petroleum products exported to the quantity produced in the United States, in 1920.

Table 102 indicates the extent to which foreign markets are essential to give an adequate outlet to the leading petroleum products produced, especially kerosene and lubricants. Exports of gasoline relative to production were fairly steady over the past few years, whereas the ratio for fuel oil showed a declining tendency, while the ratios for kerosene and lubricants displayed a marked decline during the war years of 1916–18 with an advancing tendency thereafter.

The Function of Exports.—The purpose of exports from a trade standpoint is to give outlet to surplus domestic production, thus maintaining sufficient taut-

ness between supply and demand to sustain prices. In normal times, also, an industry enjoying a large export trade is more stable than one more dependent upon domestic markets, as the business cycles in different countries do not coincide, and the composite demand is more nearly equalized. A secondary purpose is the placement of products in a more profitable market than is afforded at home.

There is a more fundamental function of an economic character, especially true of the oil industry, in the part played by exports in sustaining a more nearly balanced outlet for joint-products and

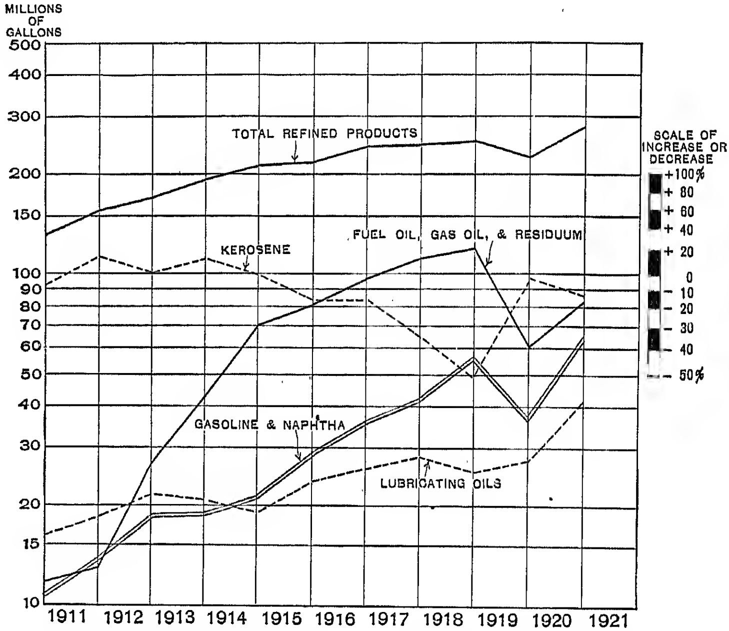


Fig. 105.—Exports of petroleum products from the United States by years 1910–1920.

in stimulating the commercial flow of products ahead of the production of crude petroleum. For example, the output of crude petroleum has mounted so rapidly, under a stimulus arising only in part from demand, that domestic markets for refined products were unable to keep pace; thus the vigorous construction of foreign markets became an economic necessity, as exemplified in the efforts that have gone into sending kerosene to the four corners of the globe. Of recent years, also, when the domestic demand for gasoline has been increasting more rapidly than the demands for the joint-products of gasoline, a foreign outlet for kerosene, fuel oil, and lubricants has tended to better proportionate a demand thrown badly out of

balance by the phenomenal rise of automotive transportation in this country.

Growth of Exports.—The trend of exports for the principal petroleum products over the past decade is presented in Fig. 105. It is there seen that up to 1918 the volume of fuel oil and gasoline exported was increasing sharply, while the shipments abroad of lubricating oils were growing at a slower ratio, with exports of kerosene declining. The effect of the war was strongly pronounced only for kerosene, which suffered because of the difficulty of access to far eastern markets. The termination of the war, however, reversed the situation, sharply curtailing in 1919 the exports of gasoline and fuel oil, at the same time sending the exports of kerosene upward toward a pre-war normal. This sharp reversal of export conditions in 1919 had a marked effect upon the domestic situation, contributing to the laxity of the gasoline and fuel oil market and to the strength of the kerosene market. In 1920, in spite of the continuation of unstable conditions abroad, the foreign shipments of gasoline, fuel oil, and lubricants showed notable increases over 1919, kerosene only falling away in some measure.

The volume of refined oils exported from 1910–1920 is given in Table 103.

TABLE 103.—EXPORTS OF THE PRINCIPAL PETROLEUM PRODUCTS FROM THE UNITED STATES BY YEARS, 1910–1920

(*In millions of gallons*)

Year	Gasoline and Naphtha	Kerosene	Fuel Oil	Lubricating Oils
1910	101	940	118	164
1911	137	1112	134	183
1912	186	1026	266	216
1913	188	1119	427	208
1914	210	1010	704	192
1915	282	837	812	240
1916	356	855	964	261
1917	416	658	1125	280
1918	559	491	1201	257
1919	372	979	618	275
1920	635	862	847	411

Value of Exports.—The value of the principal petroleum products exported from the United States from 1910–1920 is shown in Table 104. A graphic comparison of the value of these exports in 1913,

1919, and 1920 is given in Fig. 106, which emphasizes the notable increase over the period under view, the value of refined oil exports

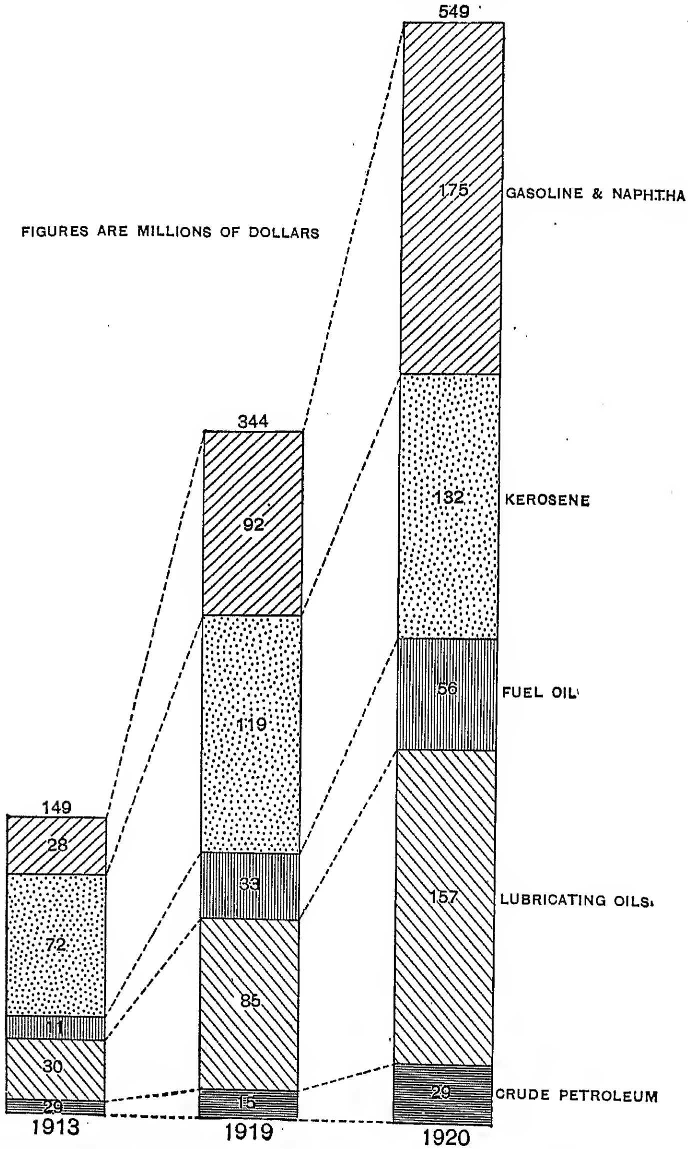


FIG. 106.—Value of petroleum products exported from the United States in 1913, 1919, and 1920.

roughly doubling the 1913 figures in 1918, and trebling the 1913 record in 1920. Fig. 106 also brings out the marked advance in the value

of the lubricating oils exported in 1920, as compared with 1919 as well as relative to the increases registered for the other petroleum products.

TABLE 104.—VALUE OF THE PRINCIPAL PETROLEUM PRODUCTS EXPORTED FROM THE UNITED STATES BY YEARS, 1910–1920

(In millions of dollars)

Year	Gasoline and Naphtha	Kerosene	Fuel Oil	Lubricating Oils
1910	8.41	55.6	3.73	20.9
1911	11.5	61.1	3.88	23.3
1912	20.5	62.1	6.60	28.3
1913	28.1	72.0	11.1	29.6
1914	25.3	64.1	19.2	26.3
1915	33.9	50.0	22.5	32.5
1916	68.7	55.9	27.1	43.0
1917	93.1	49.0	45.7	57.6
1918	140	50.4	66.6	75.6
1919	92.0	119	32.6	85.1
1920	175	132	55.9	157

Comparison of Export and Domestic Prices.—The prices realized on the petroleum products exported may be determined by dividing the value of exports by the gallonage. A comparison of the average

TABLE 105.—COMPARISON OF AVERAGE EXPORT PRICES WITH DOMESTIC PRICES FOR THE PRINCIPAL PETROLEUM PRODUCTS BY YEARS, 1913–1920

Year	Gasoline and Naphtha		Kerosene		Fuel Oil		Lubricating Oils	
	Average Export Price, Cents per Gallon	Average Domestic Price, Cents per Gallon	Average Export Price, Cents per Gallon	Average Domestic Price, Cents per Gallon	Average Export Price, Dollars per Barrel	Average Domestic Price, Dollars per Barrel	Average Export Price, Cents per Gallon	Average Domestic Price, Cents per Gallon
1913	14.9	15.6	6.4	7.9	1.09	1.06	14.2	15.4
1914	12.0	13.0	6.3	7.6	1.15	.90	13.7	15.6
1915	12.0	11.7	6.0	7.1	1.16	.72	13.5	14.9
1916	19.3	18.9	6.5	7.9	1.19	1.04	16.5	18.3
1917	22.4	20.6	7.4	8.5	1.70	1.57	20.6	19.5
1918	25.0	21.7	10.3	10.2	2.33	2.01	29.4	30.9
1919	24.7	22.2	12.2	12.7	2.22	1.59	30.9	32.2
1920	27.6	26.5	15.2	17.1	2.77	2.79	38.2	49.0

export prices so determined with the average domestic prices calculated from price quotations is given in Table 105.

It may be observed that export prices for gasoline and fuel oil have in general run slightly above the corresponding domestic prices, while the reverse has tended to be true of kerosene and lubricating oils.

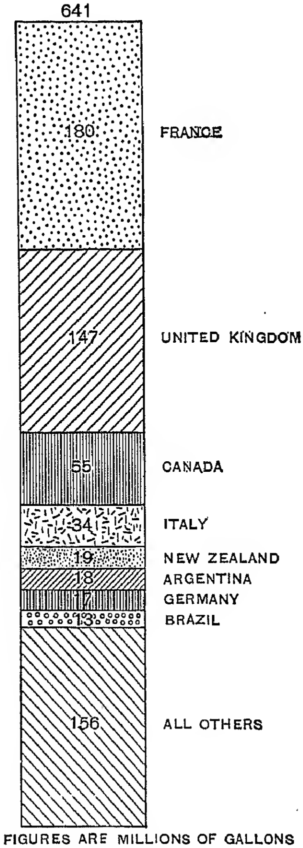


FIG. 107.—Destination of gasoline and naphtha exported from the United States in 1920.

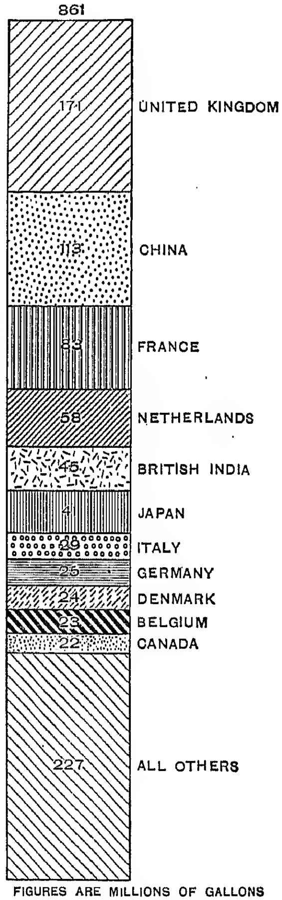


FIG. 108.—Destination of kerosene exported from the United States in 1920.

Distribution of Exports.—The countries to which the exports of mineral oils are consigned are given in full detail in the reports of the Bureau of Foreign and Domestic Commerce.[1] A summary of

[1] Monthly Summary of Foreign and Domestic Commerce, and Foreign Commerce and Navigation of the United States (Annual).

such data for the year 1920 is given in graphic form in Figs. 107–110.

Fig. 107 shows that over half of the gasoline exported in 1920 went

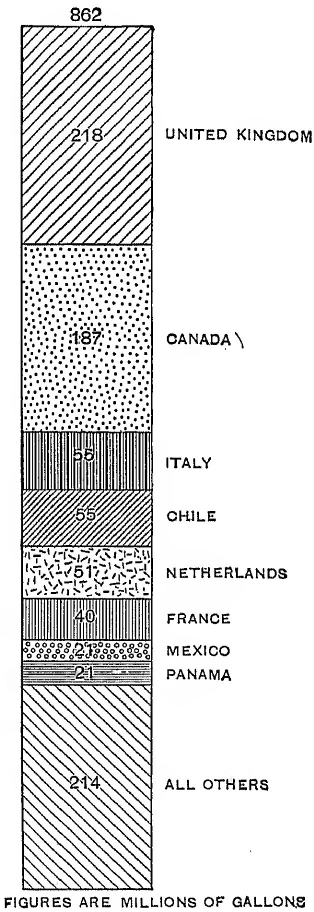


FIG. 109.—Destination of fuel and gas oil exported from the United States in 1920.

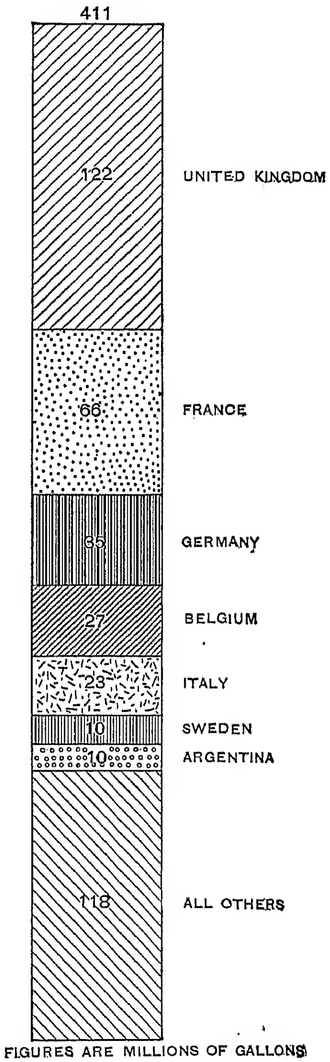


FIG. 110.—Destination of lubricating oils exported from the United States in 1920.

to France and the United Kingdom. Germany is also shown as having entered the market in appreciable degree.

In Fig. 108 is seen a more equable division of kerosene among a greater number of nations. China appears as a large foreign consumer of this product, second only to the United Kingdom. Germany ranks along with Italy and Denmark.

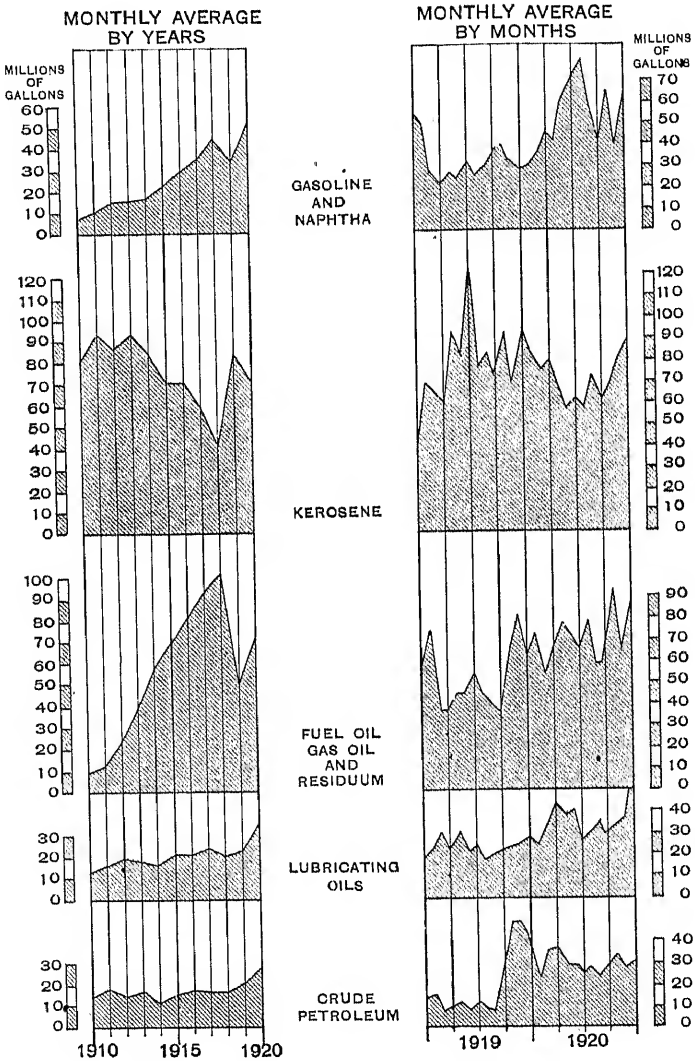


FIG. 111.—Exports of mineral oils from the United States.

The destination of fuel oil exports is analyzed in Fig. 109, which shows the United Kingdom and Canada as the leading recipients, with Italy, Chile, Netherlands and France as taking second place.

TABLE 106.—EXPORTS OF THE PRINCIPAL PETROLEUM PRODUCTS FROM THE UNITED STATES

Data from Bureau of Foreign and Domestic Commerce

(In millions of gallons)

Monthly Average	Gasoline and Naphtha	Kerosene	Fuel Oil (Including Gas Oil and Residuum)	Lubricating Oils
1913	16	93	36	17
1914	18	84	59	16
1915	24	70	68	20
1916	30	71	80	22
1917	35	55	94	23
1918	47	41	100	21
1919	31	82	52	23
January	48.0	68.4	74.6	21.5
February	27.0	67.3	36.9	26.9
March	22.4	54.3	36.9	21.3
April	27.6	93.2	45.9	30.1
May	26.1	79.9	42.6	19.1
June	31.8	124	54.2	25.1
July	24.5	76.2	44.8	15.5
August	29.6	84.0	39.0	20.7
September	34.7	75.6	38.6	19.7
October	40.5	94.3	65.9	23.9
November	31.0	65.5	81.6	26.3
December	29.2	93.3	56.6	27.5
1920	53	72	71	34
January	30.6	81.2	74.6	23.7
February	32.3	75.7	52.1	33.2
March	47.1	79.7	67.8	44.2
April	43.5	67.7	78.3	38.7
May	69.0	56.5	69.8	41.6
June	68.5	62.0	67.8	26.5
July	81.8	58.5	78.9	28.3
August	58.7	74.6	58.8	34.2
September	39.9	62.7	59.9	28.5
October	65.3	69.6	92.5	32.5
November	40.0	80.7	65.2	34.4
December	66.8	89.7	84.2	50.5
1921				
January	54.5	79.1	110	37.9
February	53.6	68.2	72.9	30.5
March	47.1	63.9	69.3	14.7
April	57.0	58.8	72.3	22.6
May	40.5	51.9	50.6	16.8
June	38.6	64.2	62.1	15.1
July	29.0	36.0	76.8	18.9

Mexico and Panama are interesting names to find included, since the first-named is herself a prominent producer of fuel oil.

Fig. 110 shows the distribution of American-made lubricating oils, which in 1920 went largely to the United Kingdom, France, Germany, Belgium, and Italy; but small quantities penetrated practically every country in which manufacturing is carried on. If the industrial activity of the United States is approximately equal to that of the rest of the world, as would appear to be the case from a comparison of the energy materials used here and abroad, the export figures indicate that roughly half of all foreign commerce and industry is lubricated by the products of American petroleum. In terms of world figures, these estimates go to show that approximately three-quarters of the lubricating needs of the entire world are dependent upon the American oil industry.

Current Trend of Exports.—The trend of exports of the principal petroleum products by months during 1919 and 1920 is shown in Fig. 111 in a form facilitating comparison, the supporting data being presented in Table 106. The data and their graphical interpretation are presented as an example of a convenient method for following the situation currently.

Future of Petroleum Exports.—The outstanding foreign market for petroleum products is Europe, although considerable quantities of kerosene go to the Far East, particularly China, and South America is coming in for a growing share of the mineral oils sent abroad. Since the armistice, European credits have been in an unsettled condition, although throughout 1919 and 1920 Europe's buying power was artificially sustained first through vast loans extended by the United States Government and later on through credits extended, in part indirectly, by American banks. For the coming few years, the foreign demand for American goods is difficult to appraise, but raw materials and products in which the ratio of labor-cost to raw material costs is low (such as refined mineral oils), may be expected to enjoy a brisker demand abroad than goods whose values are largely fabricated into them.

Taking a long-range view ahead, we are faced by an ultimate shortage of crude petroleum in respect to the requirements of the domestic market alone, in contrast to the conditions of the past in which an oversupply was forced to seek relief abroad. As foreign oil-fields become more actively productive, and American oil-fields commence their inevitable decline, the proportions of American petroleum products shipped abroad may be expected to assume a waning rôle.

CHAPTER XVII

PRICES OF PETROLEUM AND ITS PRODUCTS

Introduction.—For the purpose of analyzing the price relations ships of crude petroleum and its products, the period of 1913–1921 was selected, and weighted average monthly prices for the commodities shown in Table 107 were calculated from the weekly quotation- appearing in trade journals.

TABLE 107.—DATA USED IN PRICE ANALYSIS

Commodity	Quotation	Composition of Average	Source of Data
1. Crude petroleum...	At wells	Five grades	National Petroleum News
2. Gasoline..........	Tank-wagon	Five cities	National Petroleum News
3. Kerosene..........	Tank-wagon	Five cities	National Petroleum News
4. Fuel oil...........	At refinery	Five locations	National Petroleum News
5. Lubricating oils....	Jobbing	Five grades	Oil, Paint and Drug Reporter
6. Petroleum products.	....	Average of Nos. 2, 3, 4, and 5	
7. All commodities....	Wholesale	327 commodities	Monthly Labor Review, U. S. Bur. Lab. Stat.

The weighted average prices so obtained were then recalculated in percentages of the respective average prices for the year 1913, thus getting series of index numbers which render the various price trends directly comparable with one another, as well as with indices of prices in general which are similarly compiled by the Government and other agencies. An added advantage of this method of treatment is that reference may at all times be had to the pre-war price-level of 1913.

The price data presented in this chapter are a continuation, with some minor modifications, of the price figures published by the U. S. Fuel Administration and War Industries Board in 1919, where reference to the detailed figures for the period 1913–1918 may be had.[1]

[1] Pogue and Lubin, Prices of Petroleum and Its Products During the War, U. S. Fuel Administration, Washington, 1919, 55 pp.; also published by the War Industries Board as Part 36 of History of Prices During the War. A portion of the present discussion is based upon that investigation.

TABLE 108.—INDEX NUMBERS OF THE PRICES OF CRUDE PETROLEUM AND ITS PRINCIPAL PRODUCTS IN THE UNITED STATES BY MONTHS, 1913–1921

(Prices for 1913 = 100)

	Crude Petroleum at Wells	Petroleum Products	Gasoline Tank-wagon	Kerosene Tank-wagon	Fuel Oil at Refinery	Lubricating Oils, Jobbing	All Commodities, U. S. Bur. Labor Stat.
1913, Year....	100	100	100	100	100	100	100
Months:							
January...	87	101	101	99	102	100	100
February..	95	101	103	99	100	100	100
March....	100	101	104	99	100	100	99
April......	99	102	104	99	105	100	98
May......	100	102	103	101	104	100	98
June......	100	101	103	101	101	100	100
July......	101	101	100	101	100	100	100
August....	103	100	99	101	102	100	101
September.	104	100	99	101	97	100	102
October...	104	99	99	101	96	100	101
November.	104	98	96	101	99	100	101
December.	106	97	93	99	96	101	99
1914, Year....	82	89	83	97	85	101	100
Months:							
January...	107	97	94	99	99	100	100
February..	108	96	93	99	100	100	99
March....	106	95	92	99	98	99	99
April......	100	95	91	99	93	102	98
May......	83	93	90	97	91	102	98
June......	77	91	85	97	90	102	99
July......	75	88	81	95	83	102	100
August....	75	85	78	90	80	102	103
September.	67	84	77	95	73	102	104
October...	62	83	75	95	71	102	99
November.	61	82	73	95	70	102	98
December.	61	82	73	95	68	102	98
1915, Year....	65	80	75	90	68	97	101
Months:							
January...	62	80	73	92	67	97	99
February..	63	78	72	90	66	95	101
March....	58	76	69	90	61	95	99
April......	56	76	69	87	62	95	100
May......	55	76	69	86	62	95	101
June......	55	76	69	86	62	95	99
July......	55	75	66	89	64	95	101
August....	59	76	67	89	65	95	100
September.	73	78	71	90	66	95	99
October...	77	85	82	91	70	100	101
November.	80	92	91	94	83	100	103
December.	92	98	100	99	85	104	106

TABLE 108.—INDEX NUMBERS OF THE PRICES OF CRUDE PETROLEUM AND ITS PRINCIPAL PRODUCTS IN THE UNITED STATES BY MONTHS, 1913–1921—(*Cont.*)

	Crude Petroleum at Wells	Petroleum Products	Gasoline Tank-wagon	Kerosene Tank-wagon	Fuel Oil at Refinery	Lubricating Oils, Jobbing	All Commodities, U. S. Bur. Labor Stat.
1916, Year....	117	114	121	101	98	119	124
Months:							
January...	108	104	111	101	99	103	110
February..	115	109	107	102	101	103	112
March....	123	113	125	102	102	101	114
April......	126	113	127	105	98	101	117
May......	130	119	129	105	88	127	118
June......	130	119	129	105	90	127	119
July......	129	119	129	102	91	127	119
August....	112	118	127	100	91	127	123
September.	101	114	120	98	95	127	128
October...	103	113	116	98	98	127	134
November.	106	114	114	95	109	127	144
December.	117	114	114	96	111	127	146
1917, Year....	155	130	132	108	147	127	176
Months:							
January...	130	120	122	99	123	127	151
February..	147	125	129	102	130	127	156
March....	148	126	130	105	131	127	161
April......	148	127	132	105	131	127	172
May......	149	129	132	108	133	127	182
June......	151	129	132	108	138	127	185
July......	152	132	132	108	157	127	186
August....	152	132	132	108	157	127	185
September.	170	133	135	113	157	127	183
October...	170	135	135	111	165	127	181
November.	170	135	135	113	166	127	183
December.	170	137	135	118	175	127	182
1918, Year....	194	160	139	130	189	201	196
Months:							
January...	174	152	135	124	180	183	185
February..	177	154	135	124	179	195	186
March....	184	156	135	124	179	199	187
April......	193	158	135	124	187	202	190
May......	196	162	139	129	197	202	190
June......	196	162	139	129	198	202	193
July......	196	162	139	129	198	204	198
August....	197	163	141	134	193	206	202
September.	204	164	142	136	195	206	207
October...	204	164	142	136	194	206	204
November.	204	164	142	136	185	203	206
December.	204	162	142	136	184	203	206

TABLE 108.—INDEX NUMBERS OF THE PRICES OF CRUDE PETROLEUM AND ITS PRINCIPAL PRODUCTS IN THE UNITED STATES BY MONTHS, 1913–1921—(*Cont.*)

	Crude Petroleum at Wells	Petroleum Products	Gasoline Tank-wagon	Kerosene Tank-wagon	Fuel Oil at Refinery	Lubricating Oils, Jobbing	All Commodities, U. S. Bur. Labor Stat.
1919, Year....	197	159	142	162	149	209	212
Months:							
January...	202	166	144	139	169	216	203
February..	197	161	142	139	150	216	197
March....	195	158	142	141	145	210	201
April......	192	157	142	145	135	210	203
May......	192	157	142	150	131	206	207
June......	192	157	142	155	129	207	207
July......	192	158	142	169	129	207	218
August....	192	159	142	177	131	206	226
September.	197	160	142	178	135	205	220
October...	197	160	142	182	140	205	223
November.	202	159	142	182	152	205	230
December.	208	179	142	186	237	212	238
1920, Year....	301	225	170	217	262	318	243
Months:							
January...	250	190	148	198	219	256	248
February..	260	202	152	201	219	295	249
March....	300	223	161	207	270	330	253
April......	308	228	166	211	275	334	265
May......	312	235	168	211	304	336	272
June......	312	242	172	216	299	361	269
July......	314	236	172	218	294	338	262
August....	314	238	176	229	292	334	250
September.	314	237	180	230	284	325	242
October...	314	230	180	226	258	316	225
November.	312	221	179	226	230	298	207
December.	307	215	178	226	200	292	189
1921:							
Months:							
January...	288	200	177	222	181	251	177
February..	192	176	160	189	135	218	167
March....	174	164	154	186	131	202	162
April......	176	160	151	178	131	194	154
May......	159	142	141	160	116	154	151
June......	127	137	137	146	102	154	148
July......	112	131	132	137	96	148	148
August....	110	129	129	137	97	148	152

Index numbers for six series of oil prices—crude petroleum, gasoline, kerosene, fuel oil, lubricating oils, and these four petroleum products averaged into a composite—are presented in Table 108, together with index numbers representing the run of wholesale

prices in general in the United States. The last-named series of index numbers, representing an average of 327 commodities in which due allowance is made for the relative importance of the different items, are those calculated by the U. S. Bureau of Labor Statistics and published in the Monthly Labor Review—the official measure of the country's wholesale price-level.

Price of Crude Petroleum.—The major portion of the crude petroleum produced is purchased by pipe-line companies. Nominally these companies transport the oil at tariff rates, but actually they buy the oil outright, paying the market (posted) rate which is supposed to be the delivered price at the refinery less transportation. The price in a given district is determined by the announcement, or posting, by one of the purchasing concerns of the price it will pay. When competition exists, the other purchasing concerns usually follow at once. To the base-price may be added certain premiums for quality, delivery, credit, etc., and from the base-price certain deductions are made for sand, water, etc.

In times of sharp demand, much oil is purchased at a premium above the posted price, whereas in periods of slack, quantities of oil may be purchased below the base-price. The following premiums were paid by one independent purchasing concern in the Mid-Continent field during a recent four-year period:

TABLE 109.—PREMIUMS PAID FOR CRUDE PETROLEUM BY A PURCHASING CONCERN IN THE MID-CONTINENT FIELD

(Data from Bates and Lasky)

Year	Millions of Barrels Purchased	Millions of Dollars paid in Premiums	Premium per Barrel
1917	216	18.5	8.5 cents
1918	586	134	22.9 cents
1919	841	494	58.75 cents
1920	88	23	26.12 cents

No systematic public record of the premiums paid is kept, so recourse must be had to the posted prices in determining the trend of the crude petroleum market. Index numbers representing the weighted average of the posted prices of five grades of petroleum—Pennsylvania, Illinois, Kansas-Oklahoma, Gulf Coast and California—are given in Table 108 and plotted on a ratio scale against gasoline, kerosene, fuel oil, and lubricating oils in turn in Figs. 112, 115, 116 and 117.

[1] See also Fig. 122, page 256, in which the average price of crude petroleum is plotted against the domestic production of crude petroleum.

There were nine major events in the price history of crude petroleum in the nine-year period of 1913–1921, to which the crude oils east of the Rocky Mountains were closely sympathetic, with California less definitely reactive.[1] These may be described separately as outstanding features, to which all other circumstances are subordinate, and are to be held clearly in mind as carrying a dominating influence into the price relations of petroleum products. (See Fig. 112.)

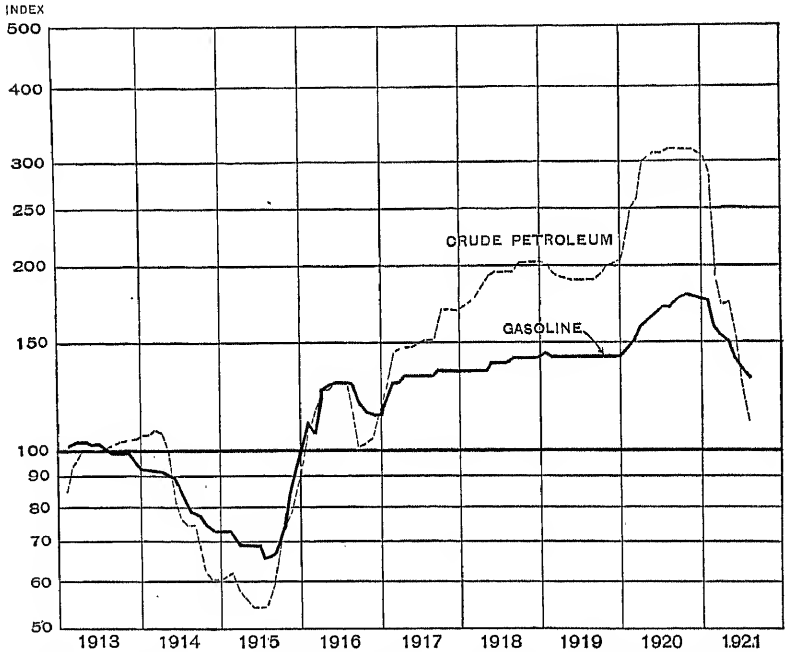


FIG. 112.—Relative prices of crude petroleum and gasoline by months, 1913–1921, in percentages of the average figures for 1913. (Average prices in 1913 = 100.)

1. *The 1913 Period of Normal Price Advance.*—The year 1913, together with the early months of 1914, was characterized by a normal advance in crude prices resulting in general from the rapidly increasing demand for petroleum, and in particular from a tendency toward declining production in the Pennsylvania field, which reacted to bring a rise in price and inclined to set the pace for the rest of the country.

2. *The Cushing Overproduction of 1914–1915.*—The strengthening markets of 1913 stimulated a country-wide drilling campaign, which culminated in the tapping of the deep sands of the Cushing

[1] It should be held in mind that the petroleum situation in California stands rather sharply apart from the rest of the country, owing chiefly to the geographic and commercial individuality of that section.

Pool in Oklahoma in April, 1914. Production "went wild"; oil in endless quantities poured forth from a multitude of wells drilled in frenzied haste. Excepting in California, the bottom dropped out of the entire crude-oil market. The price slump was unprecedented in the history of the oil industry. The effect upon the petroleum industry of the outbreak of the European war in July, 1914, was largely drowned in the flood of Cushing oil.

3. *The Recovery of 1915–1916.*—Each action has its reaction and Cushing proved no exception. By August, 1915, Cushing, while still productive, had run its course. Encouraged by an ever-accelerating demand for gasoline, and by the purchase and removal from the open market of large quantities of surplus Cushing crude, prices recuperated with even greater rapidity than they had declined, and by the end of 1915 the market was just surmounting its pre-Cushing level. This advance continued through the first quarter of 1916, but after the manner of such things overreached itself. Overstimulated drilling, especially in the Mid-Continent field, brought a surplus production with a corresponding price depression, far less serious, however, than the disastrous overproduction of the Cushing days.

4. *The Minor Slump of 1916.*—The recovery from Cushing, then, was too rapid. There came a temporary relapse, strongest in Mid-Continent prices, and the last half of 1916 saw a repetition of the Cushing depression on a minor scale. With the turn into 1917, however, the recovery was complete.

5. *The War Stimulus of 1917–1918.*—Under the stimulus of war conditions—strengthening demands, increasing production costs, eagerness to insure adequate increases in output, and the general atmosphere of increasing prices—the prices of crude advanced at intervals the country over, until in early 1918 they attained a height in general roughly double the pre-war level. The reaction was uniform and singularly coincident on the part of the crude petroleums of the entire country.

6. *The Governmental Stabilization.*—The tendency toward price advance under war stimulus was checked with the advance of 25 cents per barrel in Mid-Continent crude in April, 1918, and definitely controlled in the latter half of 1918 by a plan of voluntary stabilization put into execution by the National Petroleum War Service Committee representing the petroleum industry, and the Oil Division of the United States Fuel Administration representing the Government.[1] Prices were thus stabilized and brought under check

[1] For a detailed account of this interesting example of industrial administration consult Pogue and Lubin, Prices of Petroleum and Its Products During the War, pp. 26–29.

on the assumption that further advances would not serve as a sufficient additional stimulus to production to justify the cost to the public.

7. *The Post-war Reaction of 1919.*—The closing year of the war, with its insistent demands for gasoline and fuel oil, strongly stimulated the production of crude petroleum and, following the armistice, 1919 opened with a bountiful output that faced a peace-time adjustment in requirements. The demand for gasoline, adjusting itself easily to the changed condition, went on unabated, but the demand for fuel oil fell away, leaving an oversupply of this commodity. In consequence, the price of light crudes, productive of gasoline, suffered no recession, but the price of heavy crudes such as those of the Gulf Coast fell slightly, so that the composite curve shows a moderate sagging during the year.

8. *The Boom Period of 1920.*—In late 1919, partly because of the period of inflation upon which the business of the entire country had entered and partly as a result of a demand for fuel oil which had been actively stimulated by the efforts of the oil industry as well as by the circumstances of a disastrous coal strike, the crude oil market showed a gathering strength which culminated in a sharp and almost unprecedented rise during the first quarter of 1920. Oil-field activity speeded up to a white heat, the prices of refined products leaped forward as if released from restraint, and the entire field of oil became involved in a period of frenzied expansion on a scale never before so fully experienced. Then came deflation and liquidation in the industrial structure of the entire country. But oil persisted as if immune. The highest levels in crude-oil prices were not attained until July; the effect of these rising prices were cumulative. The domestic output of crude petroleum was progressively stimulated, at the same time that shipments of crude petroleum from Mexico were coming to this country in unprecedented volume. An oversupply, on the one hand, an industrial depression on the other—still the price of crude petroleum held high. Not until the close of the year did crude oil prices weaken, and then only the heavy crudes most directly affected by the flood of oil from Mexico. The year closed with the price structure of crude petroleum overripe for a tumble.

9. *The Price Tumble of Early 1921.*—During the first two months of 1921 the inevitable happened. Between the first week in January and the last week in February the average price of crude cascaded from \$3.50 to \$1.98 a barrel, a drop of 43 per cent. In all parts of the country but California the declines were precipitous. In a few brief weeks, the levels of early 1918 were attained. The rise of

1920 and more had been eliminated. Another price cycle had run its course. And just as the price rise of early 1920 overreached itself and led to the subsequent break in the crude-oil market, so the price reaction of 1921 went to undue length, laying the basis for a sensational rise in price later on.

Price Compared with Cost of Drilling.—The price of crude petroleum, in spite of many downward reactions, has been trending sharply upward at an average rate of 22 per cent annually during the eight-year period 1913–1920. (See Fig. 121, page 255.) This upward tendency is due mainly to (*a*) the increasing cost of drilling arising from the greater number of well-feet per barrel, (*b*) the increased cost of materials and labor, and (*c*) the mounting demand for oil products. It is difficult to disentangle and separately appraise these three factors, but as time goes on (*a*) and (*c*) may be expected to contribute a further impetus upward, although (*b*) is tending downward. The items of cost in drilling a typical oil-well 2500 feet in depth in the Mid-Continent field, in percentages of the average figures for 1913, are presented in Table 110 for successive years from 1913 to 1920, which gives a measure of factor (*b*) noted above.

TABLE 110.—COST OF DRILLING AND EQUIPPING A TYPICAL 2500-FOOT WELL IN THE MID-CONTINENT FIELD BY YEARS, 1913–1920

(Data from Bates and Lasky, after F. W. Swift)

(*In percentages of the figures in 1913*)

	1913	1914	1915	1916	1917	1918	1919	1920*
Casing	100	97	96	130	184	205	258	258
Contract drilling	100	166	180	216	246	277	382	382
Labor	100	108	111	119	145	172	232	278
Miscellaneous	100	106	106	121	154	185	225	223
Total	100	113	115	141	181	208	267	271

* Estimated by Bates and Lasky.

The total cost of drilling as presented in Table 110 in percentages of the 1913 cost, is plotted in Fig. 113 against the average price of Mid-Continent crude similarly expressed. This chart shows how the price movement in periods of oversupply, such as the year 1915, lags behind drilling costs, and in periods of strong demand such as 1920 rises above the cost of drilling level.

The Price of Gasoline.—As representative of the wholesale price of gasoline, the tank-wagon prices at five populous cities in various

parts of the country—New York, Baltimore, Chicago, Kansas City and San Francisco—were averaged and recalculated in percentages of the average price in 1913. The index numbers so obtained are given in Table 108, and plotted in comparison with the price trend of crude petroleum in Fig. 112. It cannot be emphasized too strongly that gasoline is a joint product with kerosene, fuel oil, and lubricants, and accordingly that the price of gasoline cannot be interpreted as a separate matter, but is intelligible only in terms of price fluctuations of crude petroleum on the one hand, and of kerosene, fuel oil, and lubricants on the other.

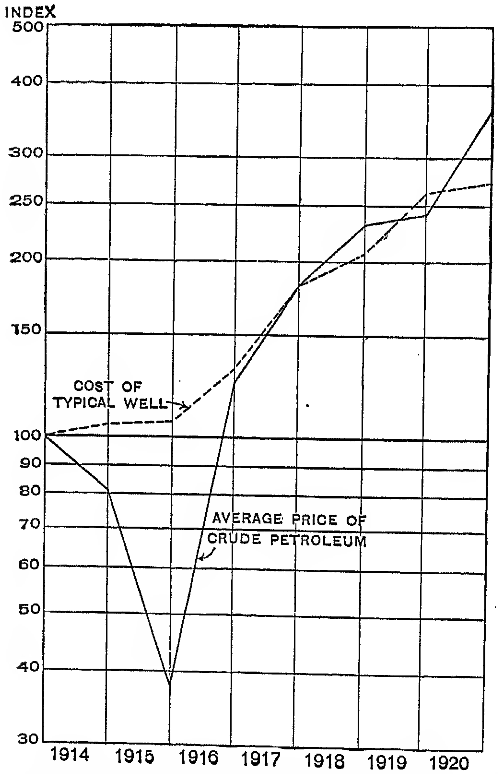


FIG. 113.—Comparison of the increase in cost of a typical well with the increase in price of crude petroleum in the Mid-Continent Field, 1913–1920; data from Bates and Lasky. (Figures for 1913 = 100.)

The outstanding features in the course of gasoline prices are eight in number.

1. *The Relative Stability of 1913.*—Gasoline commenced 1913 with slight advances in price in keeping with the upward trend in the crude market, but after the first quarter of the year, gasoline prices fell away gently but steadily in opposition to the continued upward trend of crude. The departure, however, was slight and to be attributed to local variations, perhaps fortuitous, and certainly with little, if any broad significance. This period, on the whole, was uneventful and characterized by stability.

2. *The Cushing Depression.*—The gasoline response to the Cushing overproduction was immediate and striking. With the serious impairment of the crude-oil market, the price of gasoline responded with an almost parallel slump.

3. *The Recovery of 1915–1916.*—Closely paralleling the recovery of the crude market following the culmination of the Cushing episode, and as a result of the same range of causes, gasoline advanced over 60 per cent between July, 1915, and May, 1916, attaining a price-level scarcely less than that prevailing at the end of 1918. The suddenness of the advance in respect to a product in universal use, following so closely upon the heels of an era of cheap gasoline, created country-wide interest and concern and led to an investigation on the part of the Federal Trade Commission, which reported "that a decreasing supply of light crudes, coupled with increasing foreign and domestic demands, explains a part of the advance in gasoline prices during 1915, but that part of the advance in certain sections at least, was unnecessary and to a certain extent due to artificial conditions. . . ." But whatever the validity of these conclusions, which must be judged on their own merits, the situation, whether complicated by artificial conditions or not, was the response or, more properly, the over-response, to the lavishness of the Cushing outpouring of crude.

4. *The Relapse of 1916.*—In the latter half of 1916, gasoline shared in the relapse of crude with a slump east of the Rockies. California serenely weathered this storm, whose effects did not reach the Pacific slope.

5. *The Period of War Stress.*—The relapse of 1916, as with crude, was short-lived; gasoline recovered its former price-level in early 1917, and to the end of 1918 held a remarkably level course, as compared with the other petroleum products, and particularly with commodities in general. The Chicago market during this time showed a series of advances, reflecting, together with the situation there for kerosene, local instabilities of a significant order.

A uniform price-level for gasoline during a period when practically all other commodities were soaring is remarkable and was only attained by virtue of the joint-product character of gasoline, which permitted its potential advances to be covered by kerosene, fuel oil, and lubricants. Increases that might have come about in the last half of 1918 were forestalled by the plan of voluntary stabilization already adverted to, which reflected an indirect influence over gasoline and the other main petroleum products.

6. *The Stable Level of 1919.*—Although petroleum production was stimulated by the war, the requirements for gasoline were so predominantly domestic that the coming of peace did not create an over-supply of this fuel. The price of gasoline, in consequence, maintained a nearly even level throughout 1919. The supply of gasoline was somewhat easier than in the previous year, but surplus failed

to accumulate sufficiently to create a significant downward revision in prices.

7. *The Sharp Rise of 1920.*—In 1920, in common with crude, petroleum products, and commodities in general, gasoline enjoyed a marked rise in price, but a rise of relatively temperate character in comparison with nearly all other commodities. The advance was less precipitous than that for crude petroleum, and the 1920 high was attained later in the year.

8. *The Price Decline of Early 1921.*—During the last quarter of 1920, the highly stimulated character of oil-field operations both domestic and Mexican, and the continued activity of the oil-refining industry, in the face of the gathering storm of business depression, led to an easing off of gasoline prices which broke into a sharp decline in early 1921. As gasoline had risen to lesser heights than had its joint-products and its raw material, its decline was accordingly less drastic, although the spot price of gasoline at the small refineries in many instances fell below the cost of production.

On the whole there is a notable coincidence between the price of crude and the price of gasoline. All the main features of the former are reflected in the latter, in modified form. Rarely, and only with local meaning, do the two courses run counter. Again there is a notable coincidence to be followed between gasoline prices in the various cities, the difference corresponding roughly to a transportation differential in respect to the sources of raw material, complicated by the sectional character of the gasoline market. In view of the wide difference in production costs, the varying strengths of the demands for products turned out along with gasoline, and the geographical disposition and structure of the industrial units concerned, the comparative uniformity in price is more striking than the minor divergences. But a product in universal use must normally attain a fairly uniform countrywide level, leaving its joint-products to level off the differences in production costs; and hence it is not surprising that gasoline shows greater price uniformity than other petroleum products.

The Price of Kerosene.—Since nearly half of the kerosene produced in the United States is exported, conditions abroad weigh heavily in influencing the domestic market. The average domestic price by years from 1913–1920 is compared graphically with the average export price in Fig. 114, which shows a fair correspondence between the two, with a tendency for the export price to lag slightly behind the domestic price.

The average domestic price of kerosene, in percentages of the 1913 figures, is shown by months for the period 1913–1921 in Table 108 and

plotted against the price of crude petroleum in Fig. 115. The price trend for kerosene shows responses to all the major events involved in the price of crude petroleum, except the slight reaction of 1919 during which period kerosene steadily advanced in price.

Throughout 1917, 1918, 1919 and most of 1920, kerosene displayed a sharp and strikingly consistent upward tendency. This course was especially notable in view of the demoralization of the normal foreign demand during much of that period. The explanation lies in part in war requirements and related causes, and in part in the rise of automotive demands for kerosene.

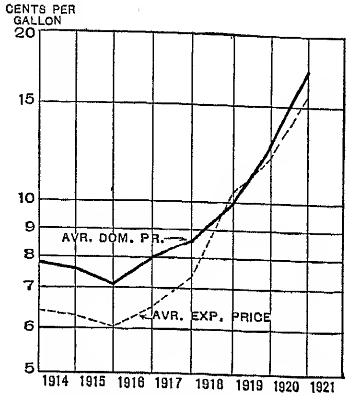


FIG. 114.—Comparison of the average export price with the average domestic price of kerosene by years, 1913–1920.

The Price of Fuel Oil.—The fuel-oil market is complicated by extensive sales on contract, with the result that much of the output changes hands at prices more or less at variance with the spot quo-

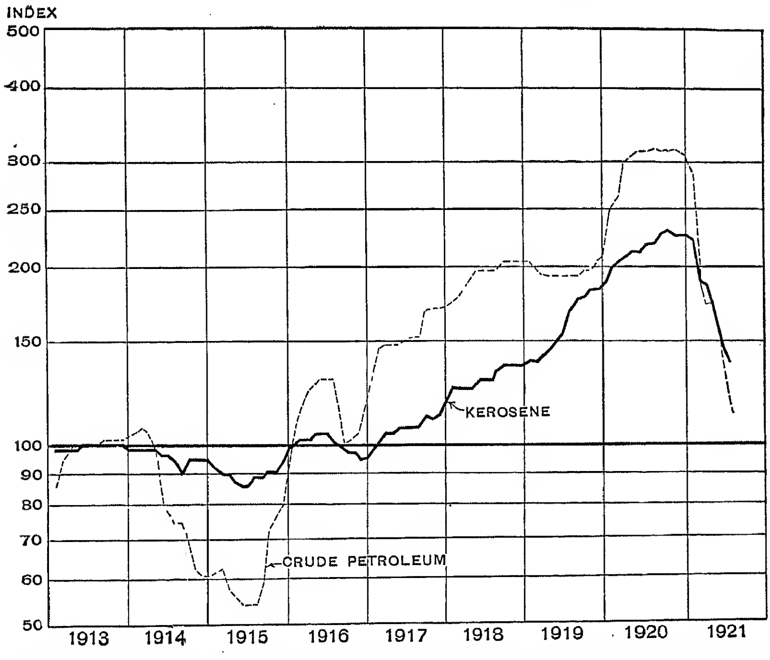


FIG. 115.—Relative prices of kerosene and crude petroleum by months, 1913–1921, in percentages of the average figures for 1913. (Average prices in 1913 = 100.)

tations. In consequence, the fuel-oil chart representing an average of spot quotations must be allowed a larger margin of error than is to be accorded the other price curves in this chapter.

Although the variations in the price of fuel oil are numerous and abrupt, there is a notable conformance, both in trend and in actual level, to the price of crude petroleum. (See Fig. 116.) This arises from the fact that crude petroleum is always open to purchase as a natural fuel oil, and hence fuel oil proper normally seeks, and can

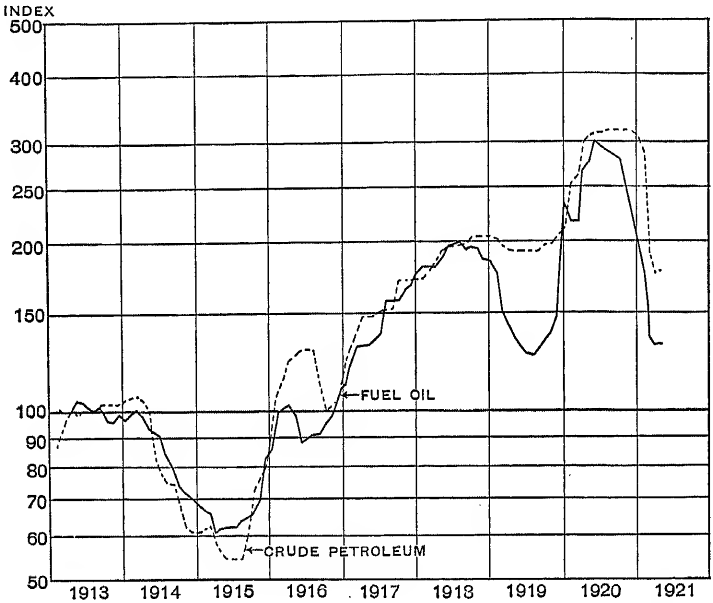


FIG. 116.—Relative prices of fuel oil and crude petroleum by months, 1913–1921, in percentages of the average figures for 1913. (Average prices in 1913 = 100.)

scarcely exceed, the level established by the price of crude. By virtue of this price affiliation the factors adduced to interpret the run of prices in regard to crude petroleum are likewise applicable to fuel oil.

In addition to the influences affecting the price of fuel oil already reviewed under the heading of crude petroleum, there should be mentioned the seasonal variations in demand, which, involving a stronger demand in winter than in summer, create a tendency for prices to rise in the autumn and to fall in the spring. This inclination for much of the period covered in Fig. 116 was hidden by stronger forces, but it came definitely into play during the winter of 1917–1918; when an unusually severe season, a coal shortage,

and a transportation tie-up sent fuel-oil prices, in the northeastern states in particular, to unprecedented levels. In consequence of a general policy toward substituting fuel oil for coal in growing degree, the demand for fuel oil became so insistent that the gasoline demand, which for some time had set the pace, was forced into second place, and the call for fuel oil, with direct reference to munitions manufacture and naval operations, became the dominant note. It was by virtue of these conditions more than any others that gasoline was freed from the responsibility of supporting the advances in the price of crude petroleum during this period.

Toward the summer of 1918, while industrial operations were still increasing apace, the demand for fuel oil became tempered by the seasonal factor, while in August the plan of stabilization of oil prices, under the joint auspices of the U. S. Fuel Administration and the Petroleum War Service Committee, came into play with due effect. Together these factors halted the advance, which turned into a decided decline when November announced the termination of European hostilities and threw the United States into a hesitant industrial mood. Thus the cycle was completed, and the motor-fuel demand reassumed the rôle of prime stimulator of the petroleum industry.

During 1919 no adequate place was found for the war-stimulated output of fuel oil, and prices fell sharply and deeply. Gasoline requirements went on increasing, thus inducing a growing output of fuel oil even in the face of the falling market. Under these circumstances, the petroleum industry projected a spectacular and effective campaign in favor of the general use of fuel oil for industrial and heating purposes. This effort began to show results toward fall and after the coal strike in the bituminous fields in November, the price of fuel oil in the single month of December recovered from its post-armistice depression, and by May, 1920, had reached a level fully 50 per cent above its 1918 attainments. Then came the break in commodity prices and the rumblings of the industrial depression that was on the way; fuel oil was among the first of the petroleum products to respond, mildly at first and then precipitously. In a few brief months the entire rise of 1919–1920 was wiped out, and by March, 1921, the low levels of 1919 had again been reached. The price rout was added to in no small degree by the flood of Mexican oil that poured into this country in ever-increasing quantities in late 1920 and early 1921.

Price of Lubricating Oils.—Lubricating oils are highly fabricated commodities, with a wide range of grades as compared with gasoline, kerosene, and fuel oil. A characteristic price average for lubricants

is difficult to calculate, as there is no centralized record correlating quantities of output with prices. A fairly satisfactory composite, however, may be made by taking a weighted average of five common grades on the New York jobbing market—paraffin 903, red paraffin, dark steam refined, spindle No. 200, and spindle No. 150. To free the view as far as possible from extraneous factors, such as the cost of containers, the prices quoted were selected to represent the basic oils from which the brands coming on the market are compounded. Sales of lubricating oils are to a considerable extent made

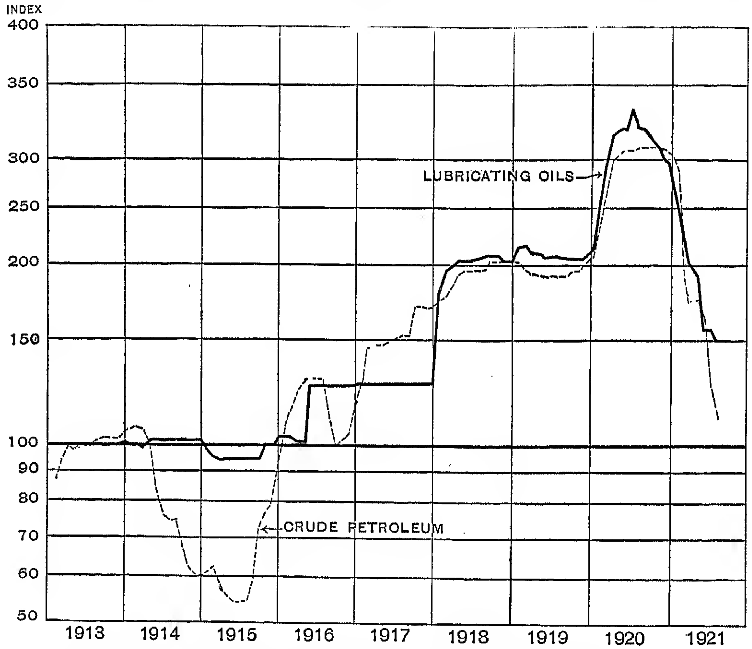


Fig. 117.—Relative prices of lubricating oils and crude petroleum by months, 1913–1921, in percentages of the average figures for 1913. (Average prices in 1913 = 100.)

on contract, but the spot prices reflect the market with reasonable accuracy.

The relative price course of lubricating oils for the period under view is shown in Table 108 and plotted against the price trend of crude petroleum in Fig. 117. Considering the fact that lubricating oils are manufactured from only a portion of the crude petroleum run to refineries in this country, a notably close coincidence in the price curves of the two is to be observed, although the price of lubricants tends to be somewhat more stable than the price of crude petroleum. Up till recent years, the supply of lubricants was derived almost

exclusively from Eastern crudes, but a growing share is now being made from the Mid-Continent, Gulf Coast, and California petroleum.

Reference to Fig. 117 shows that the price of lubricating oils held a fairly even course from the beginning of 1913 to early 1916, in the face of strong price disturbances prevailing elsewhere in the petroleum industry. In April, 1916, there came a sharp rise in price-level, following the initial recovery of the crude market from the Cushing depression and the growth of orders for future delivery. For the remainder of 1916 and practically all of 1917, lubricants

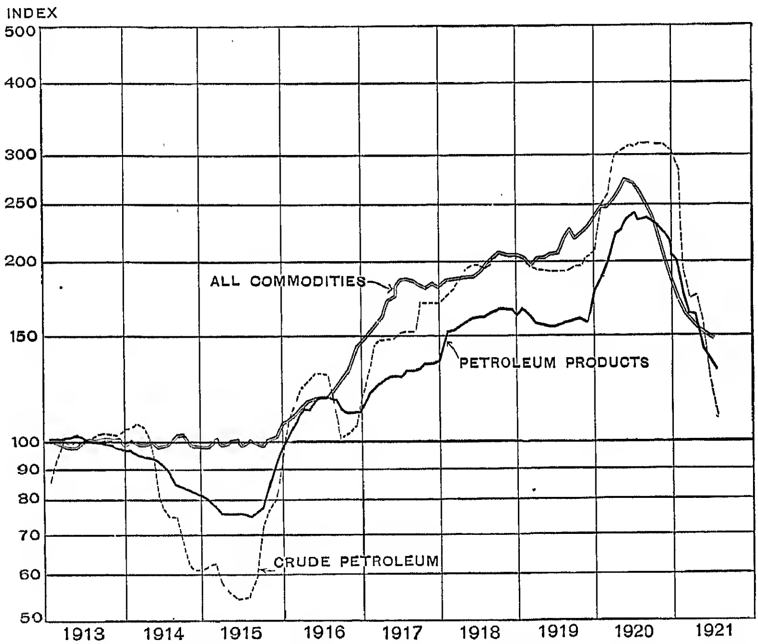


Fig. 118.—Relative prices of crude petroleum, petroleum products, and all commodities by months, 1913–1921, in percentages of the average figures for 1913. (Average prices in 1913 = 100.)

remained stable, showing few of the fluctuations elsewhere taking place. The beginning of 1918, however, saw an abrupt ascent to prices well above those of 1916–1917, with further advances in early 1918 to twice the pre-war level, to be explained by a combination of circumstances—increases in the cost of high-grade crude, general domestic conditions of stress and high costs, transportation congestion, shortages in special grades, and the ever-increasing growth of demand. From then on to late 1919 there was little change in level.

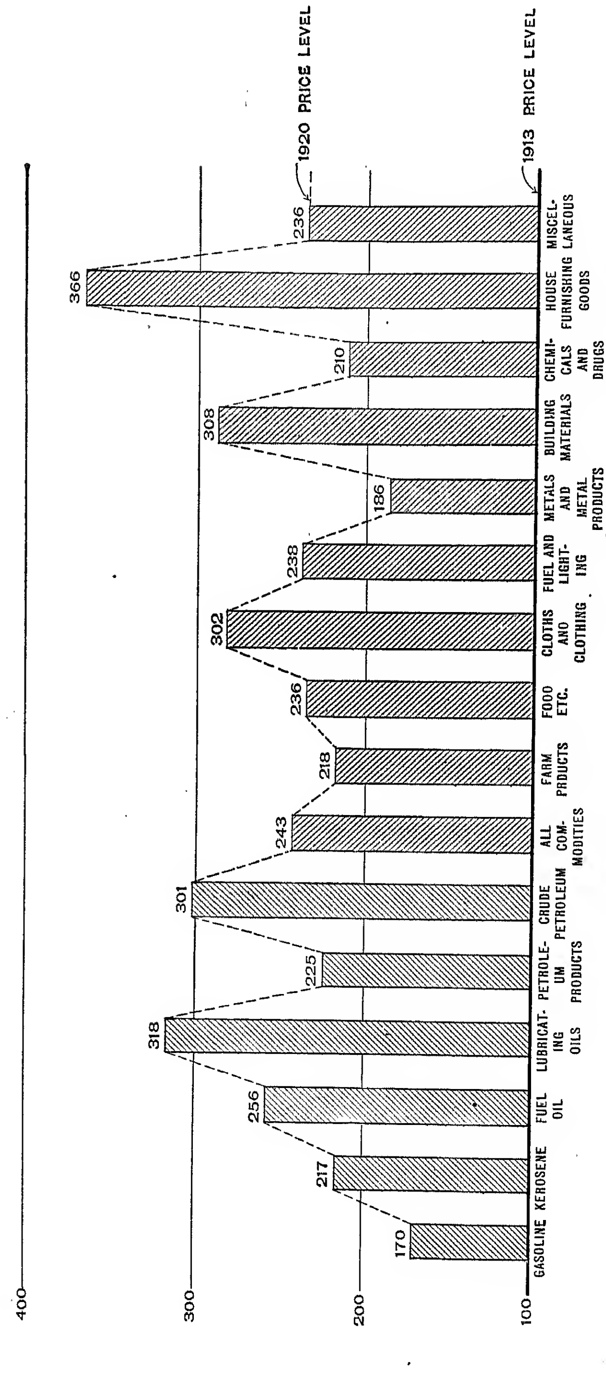


FIG. 119.—Price level of crude petroleum and its principal products in 1920 compared with various classes of commodities.

In early 1920, in sympathy with markets in general, the price of lubricants rose to unprecedented heights, surmounting the whole price structure of petroleum. But this increase was short-lived; lubricants proved to be closely sympathetic in price with commodities in general and followed the country's price-level downward during its entire descent to early 1921, thus anticipating by several months the fall in price of crude petroleum. This immediate reaction to the industrial depression is readily understandable in view of the far-reaching employment of lubricants in industry.

Relation of Oil Prices to Commodity Prices.—In order to bring the trend of prices in the petroleum industry into a still more summarized view, the relative prices for (*a*) crude petroleum, and (*b*) petroleum products (weighted average of gasoline, kerosene, fuel oil, and lubricants), are plotted in Fig. 118 against the price-level of all commodities as determined by the U. S. Bureau of Labor Statistics. An interesting conformance between the three curves is to be observed, petroleum products tending to take a position in sympathy with the trend of crude petroleum on the one hand, and with all commodities on the other. The reaction of both crude petroleum and petroleum products to the decline of commodity prices in 1920–1921 is worthy of special study, with particular regard to the sequence in the decline of the three items. It is an open question, however, whether petro-

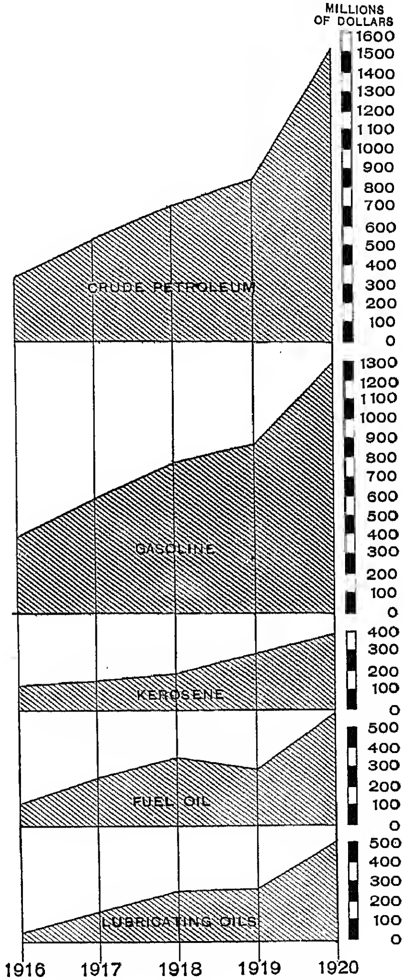


FIG. 120.—Value of the domestic production of crude petroleum and its principal products by years, 1916–1920.

leum prices will follow commodity prices throughout the entire future course of the latter, since technical factors peculiar to petroleum are shaping up which may ultimately create a price divergence.

The elevation of various groups of prices in 1920 above the pre-war level of 1913 is illustrated in Fig. 119. The price-level of gasoline is especially noteworthy in this connection.

The Value Relationships of the Petroleum Industry.—The average prices calculated for the present chapter, in conjunction with production statistics available from official sources, afford the means for evaluating the output of the American petroleum industry. The value of the crude petroleum and the principal petroleum products turned out in the United States by years from 1914–1920 is accordingly presented in Table 111.

TABLE 111.—ESTIMATED VALUE OF THE OUTPUT OF THE AMERICAN PETROLEUM INDUSTRY BY YEARS, 1914–1920

(In millions of dollars)

Year	Crude Petroleum	Gasoline	Kerosene	Fuel Oil	Lubricating Oils	Total of Four Products
1914	214*	125†	97†	84†	56†	362†
1915	179*	....‡	....‡	....‡	....‡	....‡
1916	331*	389	115	116	114	734
1917	523*	587	147	243	147	1124
1918	704*	775	186	352	260	1573
1919	850	879	298	291	273	1741
1920	1520	1294	396	580	514	2784

* U. S. Geological Survey.
† 1914 Census of Manufactures.
‡ Omitted because of the lack of production statistics for 1915.

The figures appearing in Table 111 are shown in graphical form in Fig. 120, in which a comparative view may be gained of the increase in value of crude petroleum and its principal products over a period during which the industry enjoyed a mounting output coupled with a rising price-level.

CHAPTER XVIII

RELATION BETWEEN PRICE AND PRODUCTION OF CRUDE PETROLEUM

THE production of crude petroleum depends upon many related variables such as strength of demand, difficulty of exploitation, intensity of search, element of chance, and many others. The interplay between production and the composite of these variable factors is reflected in price, and a comparison of price with production should yield results of value, although the problem of correlation is too complex to be fully solved with available data and methods of analysis. The present chapter attempts to measure the two key elements in the crude petroleum situation in the United States and to establish so far as possible the degree to which a relationship between the two exists.

The basis of the investigation is quantitative data on production and price, and qualitative data on all the other factors commonly recognized as entering into the situation. The period investigated is from 1913 to 1920, inclusive. The production data are the figures on marketed production compiled by the U. S. Geological Survey; the price data represent a weighted average of the average monthly price of five grades of crude petroleum, the original quotations being the posted price at the wells as given by the National Petroleum News.[1] The data on production and prices are presented in Table 112. The data on the price-level of all commodities are the index numbers calculated by the U. S. Bureau of Labor Statistics and published in the Monthly Labor Review.

Trend of Production, Consumption, and Price by Years.—A broad picture of the production, consumption, and average price of crude petroleum in the United States by years from 1913 to 1920 is

[1] The five grades are Pennsylvania, Illinois, Kansas-Oklahoma, Gulf Coast (Humble) and California (14°–17.9°), and the weighted average is derived according to the formula, $\frac{P+I+2K+G+C}{6}$. A more elaborate method of weighting was tried, whereby the prices were combined in proportion to the production of the respective fields, but sufficient divergence from the simpler method was not found to warrant the more laborious calculations.

TABLE 112.—MARKETED PRODUCTION AND AVERAGE PRICE OF CRUDE PETROLEUM IN THE UNITED STATES BY MONTHS, 1913–1920

(Production in millions of barrels. Price in dollars per barrel)

	1913		1914		1915		1916	
	Prod.	Price	Prod.*	Price	Prod.*	Price	Prod.	Price
January..	19.5	0.99	21.9	1.22	21.0	.71	23.1	1.23
February.	18.2	1.08	20.1	1.23	20.3	.72	22.7	1.31
March....	20.4	1.14	23.7	1.21	22.7	.66	25.5	1.40
April.....	20.6	1.13	22.9	1.14	26.1	.64	24.0	1.48
May.....	21.3	1.14	24.2	.95	22.7	.63	26.0	1.49
June.....	20.9	1.14	23.8	.88	23.4	.63	25.5	1.49
July.....	21.5	1.15	23.7	.86	24.8	.63	25.3	1.47
August...	21.1	1.18	20.6	.85	23.7	.67	25.2	1.27
September	20.5	1.19	20.1	.76	23.4	.83	25.3	1.15
October...	21.3	1.19	22.4	.71	24.0	.88	26.7	1.17
November	20.8	1.19	21.1	.70	23.8	.92	25.3	1.21
December	21.7	1.21	21.0	.70	25.1	1.05	25.9	1.33
Year.....	248	1.14	266	.93	281	.75	301	1.33

	1917		1918		1919		1920	
	Prod.	Price	Prod.	Price	Prod.	Price	Prod.	Price
January..	26.3	1.49	27.3	1.98	30.2	2.30	33.8	2.86
February.	23.7	1.67	25.9	2.01	26.9	2.24	32.7	2.96
March...	28.0	1.68	29.7	2.10	30.2	2.22	35.8	3.42
April.....	27.1	1.68	29.0	2.20	29.4	2.19	35.6	3.51
May.....	27.6	1.70	30.4	2.24	30.0	2.19	36.5	3.55
June.....	27.4	1.72	29.9	2.24	31.6	2.19	36.9	3.55
July.....	29.1	1.74	31.8	2.24	33.9	2.19	38.2	3.57
August...	29.7	1.74	30.6	2.25	33.9	2.19	39.1	3.57
September	29.6	1.74	30.4	2.33	33.7	2.24	37.5	3.57
October..	30.4	1.94	31.3	2.33	33.3	2.25	39.6	3.57
November	28.7	1.94	29.9	2.33	32.1	2.31	38.7	3.56
December	27.6	1.94	29.8	2.33	32.5	2.49	39.0	3.50
Year.....	335	1.77	356	2.22	378	2.25	443	3.44

* Monthly figures for 1914 and 1915 are approximate.

presented in Fig. 121, in which the items named are plotted by years on semi-logarithmic paper, and straight lines fitted to the three curves to indicate the average trends. The data on which Fig. 121 is based, together with corresponding index numbers, appear in Table 113. It will be observed that the average annual increase over the past eight years has been approximately 9.5 per cent for production, 12 per cent for consumption, and 22 per cent for price. It will be noted, further, that in 1920, as compared with 1919, production increased 17 per cent; consumption, 27 per cent; and price, 53 per cent.

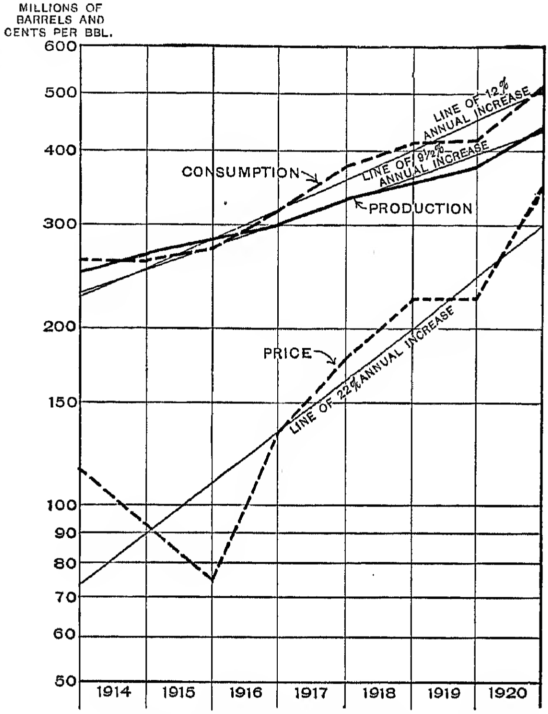


FIG. 121.—Trend of production, consumption, and price of crude petroleum, 1913–1920.

TABLE 113.—TREND OF PRODUCTION, CONSUMPTION AND AVERAGE PRICE OF CRUDE PETROLEUM IN THE UNITED STATES BY YEARS, 1913–1920

Year	Production, Millions of Barrels	Consumption, Millions of Barrels	Average Price, Dollars per Barrel	Production, Index Nos.	Consumption, Index Nos.	Average Price, Index Nos.
1913	248	262	1.14	100	100	100
1914	266	261	.93	107	100	82
1915	281	273	.75	113	104	66
1916	301	319	1.33	121	122	117
1917	335	378	1.77	135	144	155
1918	356	413	2.22	144	158	195
1919	378	418	2.25	152	160	197
1920	443	531	3.44	179	202	302

Relation of Production and Price by Months.—The relationships shown in Fig. 121 are analyzed in greater detail in Fig. 122, in which the data given in Table 112 are plotted on semi-logarithmic paper, with the trend lines as determined in Fig. 121 superimposed upon the curves. The trend lines show a reasonably satisfactory fit and indi-

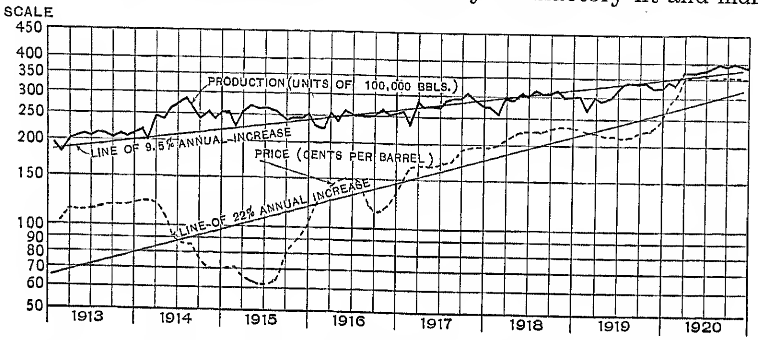


Fig. 122.—Relation of price to production of crude petroleum by months, 1913–1920.

cate that price, in general, has increased at double the rate characterizing the increase in production. If the trend lines are looked upon as representative of the normal progression of the items, the wave-like advance of the price curve will claim attention—the reaction to the Cushing overproduction, the rebound from the price recovery of 1915–1916, the 1919 reflection of the post-war adjustment and the

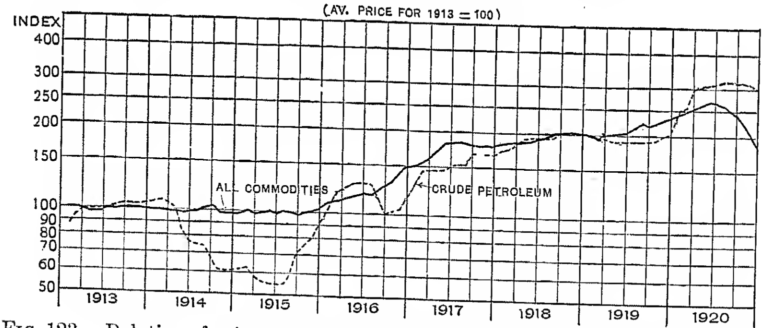


Fig. 123.—Relation of price level of crude petroleum to average of all commodities by months, 1913–1920.

flush production of North Texas, and the sharp rise of 1920 followed by a less marked increase in production.

Comparison of Price of Petroleum with all Commodities.—The rise in price of crude petroleum over the period shown is due to a growing demand, an increasing cost of exploitation, and a general advance in the country's price-level. The last-named factor may be measured

by plotting index numbers calculated from the average price of crude petroleum against index numbers representing the average wholesale price of all commodities as determined by the U. S. Bureau of Labor Statistics. These two items are shown in comparative form on a semi-logarithmic scale in Fig. 123. Two features are outstanding: The several price reactions which temporarily depressed the price of crude petroleum below the level of all commodities; and the sharp rise in the price of petroleum above all commodities in 1920.

The trend of the price relationship between petroleum and all commodities may be more strikingly shown by plotting the average

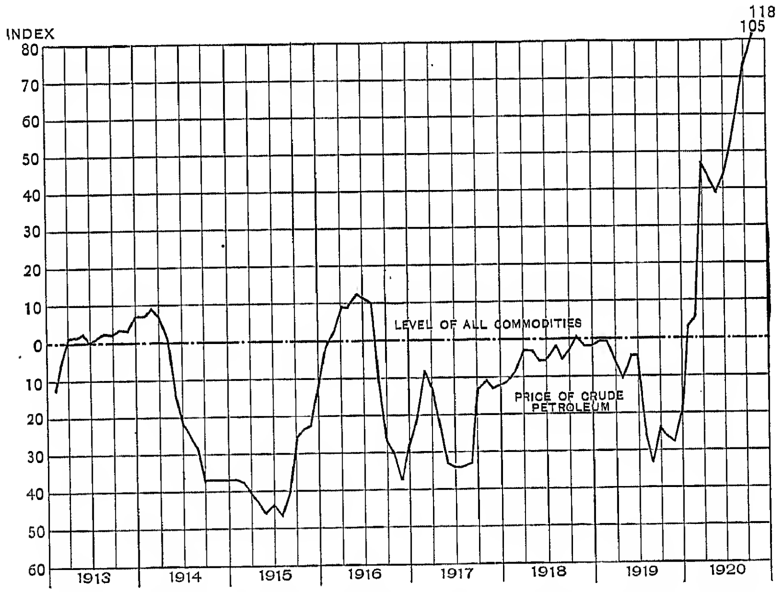


FIG. 124.—The average price of crude petroleum plotted as ordinates of the price level of all commodities, by months, 1913–1920.

price of petroleum against the price-level of all commodities taken as a horizontal line. This method of plotting accentuates the degree to which the price of crude petroleum departed from the country's price level in 1920 and serves to explain in part the recession in crude petroleum prices that came in early 1921. (See Fig. 124.)

Secular Trend of Production.—There are two simple methods of interpreting the trend of a series of items, such as production or price. The first method is that of plotting the series on semi-logarithmic paper and fitting a straight line to the curve. This method, of course, interprets the trend as a geometric progression (see Figs. 121 and 122). A second method is that of plotting the series on a natural scale and

fitting a straight line to the curve; in this instance, however, the trend line represents an arithmetic progression in which the growth is by addition instead of by percentage increase. Fig. 125 shows the production of crude petroleum interpreted by the second method, in which the line of secular trend represents a monthly increment of 179 thousand barrels. Fig. 125 emphasizes to a greater degree than does Fig. 122 the 1920 rise of production above the line of "normal" trend.

Secular Trend of Price.—In Fig. 126 the price trend of crude petroleum is also interpreted in the manner described in the preceding paragraph. Figs. 125 and 126 should be carefully compared,

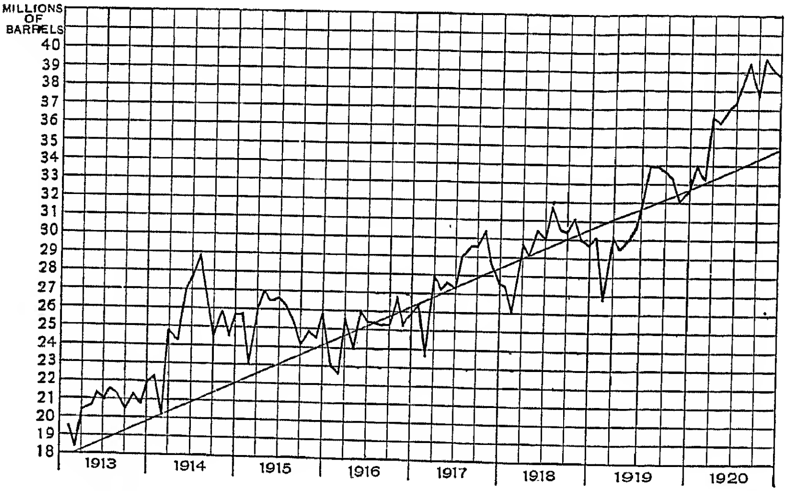


FIG. 125.—Monthly production of crude petroleum in the United States, 1913–1920, together with line of secular trend representing the "normal" rate of increase.

as they illustrate the price-production relationship on the assumption that the increases in each item are arithmetic.

Correction of Curves.—If the two lines of secular trend appearing respectively in Figs. 125 and 126 be regarded as the normal tendency of production and price during the period under study, the deviations from these lines in each instance will presumably reflect transient or new factors entering into the relationship. A comparison of the deviations from secular trend is therefore suggested. The data underlying the two curves are consequently recalculated so as to show only the deviations from secular trend, the data for production being still further corrected for seasonal variations, and the results plotted in Fig. 127. Roughly speaking, Fig. 127 eliminates the sys-

tematic upward trend in production and price, and shows merely the fluctuations from normal.

The plot of the corrected curves illustrated in Fig. 127 shows a wide divergence between production and price in 1915, following the flush production of the Cushing Pool; a resonably good coincidence in 1916, 1917, and 1918, especially in the latter two years; a complementary spread in the latter half of 1919, resulting mainly from the flush production in North Texas; and an upward divergence in 1920, with price rising roughly to three times the level of production. The chart is thought to represent an accurate measure of the extent to

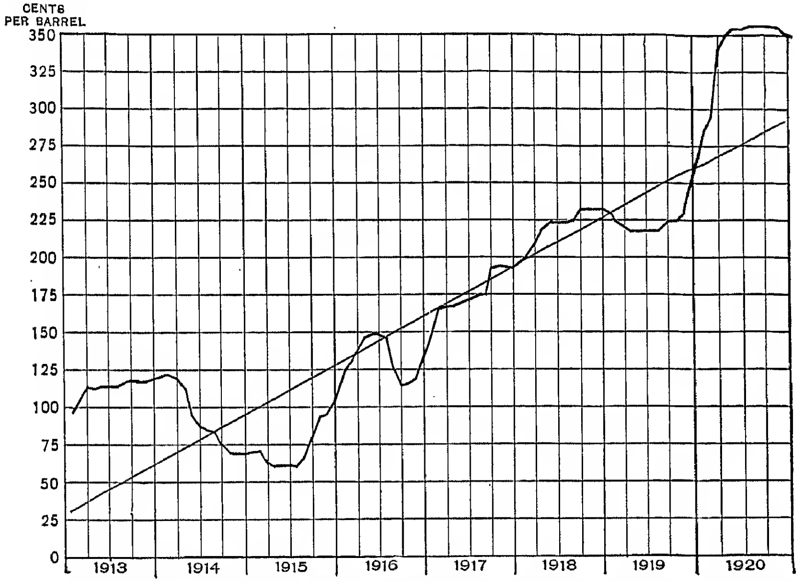


FIG. 126.—Monthly average price of crude petroleum in the United States, 1913–1920, together with the line of secular trend representing the "normal" rate of increase.

which the production of crude petroleum was overstimulated by the unduly sharp price rise in the first quarter of 1920, and to rather clearly forecast the conditions of oversupply that characterized the closing months of the year and led to the price cuts that started in December and became prominent early in 1921.

Explanation of Method of Curve Correction.—The method followed in the preceding section was suggested by a number of investigations conducted by the Harvard University Committee on Economic Research under the editorship of Warren M. Persons.[1] The

[1] See especially: An Index of General Business Conditions, The Review of Economic Statistics, April, 1919; Indices of Business Conditions, *Ibid.*,

calculations involved are rather lengthy and, for want of space, are not given here.

The seasonal variation in the production of crude petroleum determined by the method followed by the Harvard University Committee on Economic Research, is shown below, as this factor may be of general use in correcting monthly production figures. As is obvious, production fluctuates according to the number of

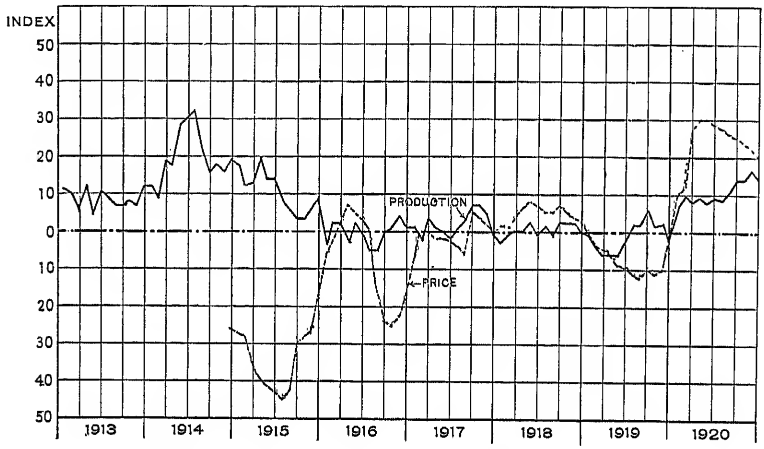


Fig. 127.—Production and average price of crude petroleum in the United States by months, 1913–1920, corrected so as to show the deviations from the "normal" rate of increase.

days in the months, and is relatively more vigorous in the warm months than in the winter. Calculations based on monthly data for the eight-year period, 1913–1920, yield the following index numbers representing the average variations of seasonal origin:

Table 114.—Index Numbers Showing the Seasonal Variations in the Production of Crude Petroleum, Based on the Years, 1913–1920

January	99.1	July	105.1
February	91.3	August	103.7
March	102.4	September	98.7
April	99.8	October	101.6
May	102.0	November	96.5
June	101.9	December	98.2
		Average	100

January, 1919; E. E. Day, An Index of the Physical Volume of Production, *ibid.*, September, October, November and December, 1920.

Comparison of Corrected Curves by Years.—In order to concentrate the results given above, with a view to eliminating all details, the yearly production, consumption, and price of crude petroleum for the period 1913–1920 were recalculated and the secular trend removed. The results were then plotted in Fig. 128, which shows the

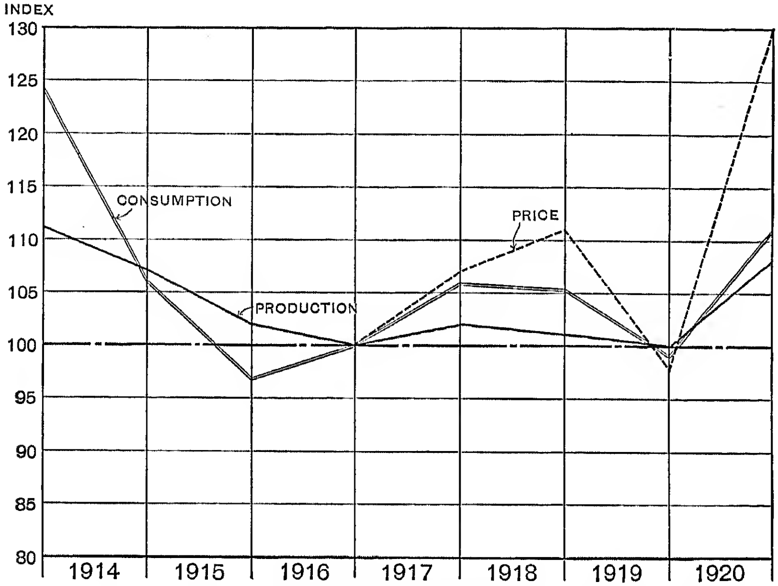


FIG. 128.—Production, consumption, and average price of crude petroleum in the United States by years, 1913–1920, corrected so as to show the deviations from the "normal" rate of increase.

relative fluctuations of the three items from normal. While a mathematical treatment of this kind must be interpreted with caution, the chart would tend to indicate that in 1920 price advanced 30 per cent higher than was necessary and led to a production of some 35 million barrels of crude oil in excess of the quantity actually needed.

CHAPTER XIX

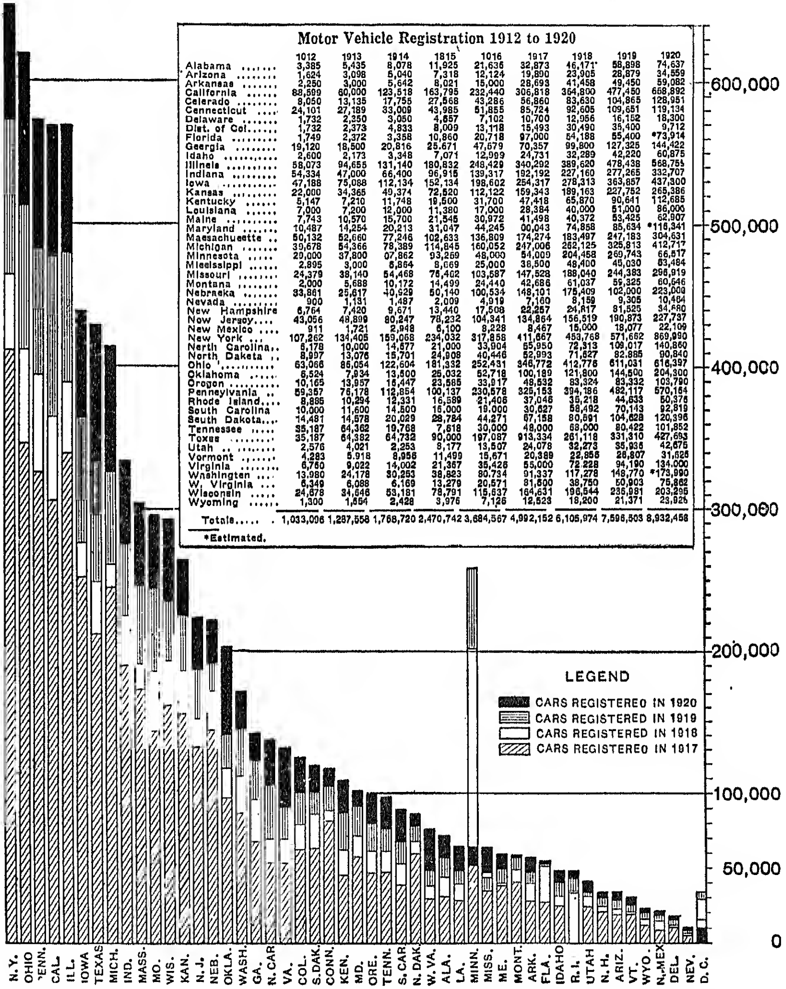
THE BEARING OF AUTOMOTIVE TRANSPORTATION UPON THE OIL INDUSTRY

THERE is no industrial parallel to the growth in output of passenger cars, trucks and tractors in the United States during the past ten years. The expansion of automotive transportation is one of the remarkable features of the twentieth century. The number of cars, trucks and tractors produced annually in the United States from 1910 to 1920 is shown in Table 115.

The approximate number of motor vehicles (passenger cars and trucks) registered during each year from 1912 to 1920 is shown in tabular and graphic form, according to states, in Fig. 129. Unfortunately the passenger cars and trucks are not separately registered in many of the states, nor is there any accurate inventory of the number of tractors in operation, but a rough apportionment of the automotive units into passenger cars, trucks, and tractors may be made on the basis of the production figures and such registration data as are available. The results of such a division are given in Fig. 130, together with the production figures, the chart therefore being an approximate measure of the remarkably rapid development of the automotive field. In rough terms, automotive transportation has grown at a rate of 40 per cent a year over the past decade. The sudden rise of such a factor has exercised a profound effect upon the petroleum industry.

Rapid Diversion of Oil Products into Automotive Channels.— Automotive transportation, of course, depends upon the oil industry for its supply of fuel and of lubricants. The growth in demand for these products caused by the expansion of automotive transportation has rapidly encroached upon the supply of oil products until in 1920 approximately 25 per cent by volume and 49 per cent by value of the output of the American oil industry was diverted into automotive channels. In the past ten years the quantity of fuel and lubricants annually consumed by automotive transportation in this country has increased from 3 million barrels to approximately 100 million barrels; while during the same period the value of the oil products consumed each year by automotive transportation has advanced

from 9 million dollars to approximately 1 billion dollars. To such an extent has the oil industry come to be the support of automotive transportation. Fig. 131 shows the rapid encroachment of automotive requirements upon the output of the oil industry.



Motor Vehicle Registration 1912 to 1920

	1912	1913	1914	1915	1916	1917	1918	1919	1920
Alabama	3,385	5,435	8,078	11,925	21,636	32,873	46,171	58,898	74,637
Arizona	1,624	3,098	5,040	7,318	12,124	19,890	23,905	28,879	34,559
Arkansas	2,250	3,000	5,642	8,021	15,000	28,693	41,458	49,450	59,082
California	88,599	60,000	123,518	163,795	232,440	306,818	364,800	477,450	658,892
Colorado	8,050	13,135	17,756	27,568	43,286	56,860	83,630	104,865	128,951
Connecticut	24,101	27,189	33,009	43,985	51,855	85,724	92,605	109,651	119,134
Delaware	1,732	2,350	3,050	4,657	7,102	10,700	12,956	16,152	18,300
Dist. of Col.	1,732	2,373	4,833	8,009	13,118	15,493	30,490	35,400	9,712
Florida	1,749	2,372	3,358	10,860	20,718	97,000	54,188	55,400	*73,914
Georgia	19,120	18,500	20,816	25,671	47,679	70,357	99,800	127,325	144,422
Idaho	2,600	2,173	3,348	7,071	12,999	24,731	32,289	42,220	60,875
Illinois	58,073	94,655	131,140	180,832	248,429	340,292	389,620	478,438	568,755
Indiana	54,334	47,000	66,400	96,915	139,317	192,192	227,160	277,265	332,707
Iowa	47,188	75,088	112,134	152,134	198,602	254,317	278,313	363,857	437,300
Kansas	22,000	34,365	49,374	72,520	112,122	159,343	189,163	227,752	265,386
Kentucky	5,147	7,210	11,748	19,500	31,700	47,418	65,870	90,641	112,685
Louisiana	7,000	7,200	12,000	11,380	17,000	28,384	40,000	51,000	86,000
Maine	7,743	10,570	15,700	21,545	30,972	41,498	40,372	53,425	62,907
Maryland	10,487	14,254	20,213	31,047	44,245	00,043	74,858	85,634	*116,341
Massachusetts	50,132	52,660	77,246	102,633	136,809	174,274	183,497	247,183	304,631
Michigan	39,678	54,366	78,389	114,845	160,052	247,006	262,125	325,813	412,717
Minnesota	20,000	37,800	07,862	93,259	48,000	54,009	204,458	269,743	66,517
Mississippi	2,895	3,000	5,864	8,669	25,000	38,500	48,400	45,030	63,484
Missouri	24,379	38,140	54,468	76,402	103,687	147,528	188,040	244,383	296,919
Montana	2,000	5,688	10,172	14,499	24,440	42,686	61,037	59,325	60,646
Nebraska	33,861	25,617	40,929	50,140	100,534	148,101	175,409	102,000	223,000
Nevada	900	1,131	1,487	2,009	4,919	7,160	8,159	9,305	10,464
New Hampshire	6,764	7,420	9,671	13,440	17,508	22,257	24,817	81,525	34,680
New Jersey	43,056	48,899	80,247	78,232	104,341	134,864	156,519	190,873	227,737
New Mexico	911	1,721	2,948	6,100	8,228	8,467	15,000	18,077	22,109
New York	107,262	134,405	159,068	234,032	317,858	411,667	453,768	571,662	869,990
North Carolina	6,178	10,000	14,677	21,000	33,904	55,950	72,313	109,017	140,860
North Dakota	8,997	13,076	15,701	24,908	40,446	52,993	71,627	82,885	90,840
Ohio	63,066	86,054	122,604	181,332	252,431	346,772	412,776	611,031	616,397
Oklahoma	6,524	7,934	13,600	25,032	52,718	100,189	121,800	144,500	204,300
Oregon	10,165	13,957	16,447	23,585	33,917	48,532	83,324	83,332	103,790
Pennsylvania	59,357	76,178	112,854	100,137	230,578	325,153	394,186	482,117	570,164
Rhode Island	8,885	10,294	12,331	16,589	21,406	37,046	35,218	44,633	50,376
South Carolina	10,000	11,600	14,500	16,000	19,000	30,627	58,492	70,143	92,819
South Dakota	14,481	14,578	20,029	28,784	44,271	67,158	80,891	104,628	120,396
Tennessee	35,187	64,362	19,768	7,618	30,000	48,000	68,000	80,422	101,852
Texas	35,187	64,382	64,732	90,000	197,087	913,334	261,118	331,310	427,693
Utah	2,576	4,021	2,253	8,177	13,507	24,078	32,273	35,936	42,675
Vermont	4,283	5,918	8,958	11,499	15,671	20,389	22,856	26,807	31,626
Virginia	6,760	9,022	14,002	21,367	35,426	55,000	72,228	94,190	134,000
Washington	13,980	24,178	30,253	38,823	80,734	91,337	117,278	148,770	*173,990
W. Virginia	6,349	6,088	6,169	13,279	20,571	81,500	38,750	50,903	75,862
Wisconsin	24,678	34,646	53,181	78,791	115,637	164,631	196,544	236,981	203,295
Wyoming	1,300	1,654	2,428	3,976	7,126	12,523	18,200	21,371	23,926
Totals	1,033,006	1,287,558	1,768,720	2,470,742	3,684,567	4,992,152	6,105,974	7,596,503	8,932,458

*Estimated.

FIG. 129.—Motor vehicles in the United States by years, 1912–1920; after Automotive Industries.

Major Financial Returns from Automotive Requirements.—At the present time approximately one-half of the revenue of the average oil company is derived from the sales of products going into automotive transportation. This proportion, however, is increasing, since

automotive requirements are expanding at a greater rate than counter-demands, with the result that a rapidly growing encroachment upon the remaining 50 per cent is coming into evidence.

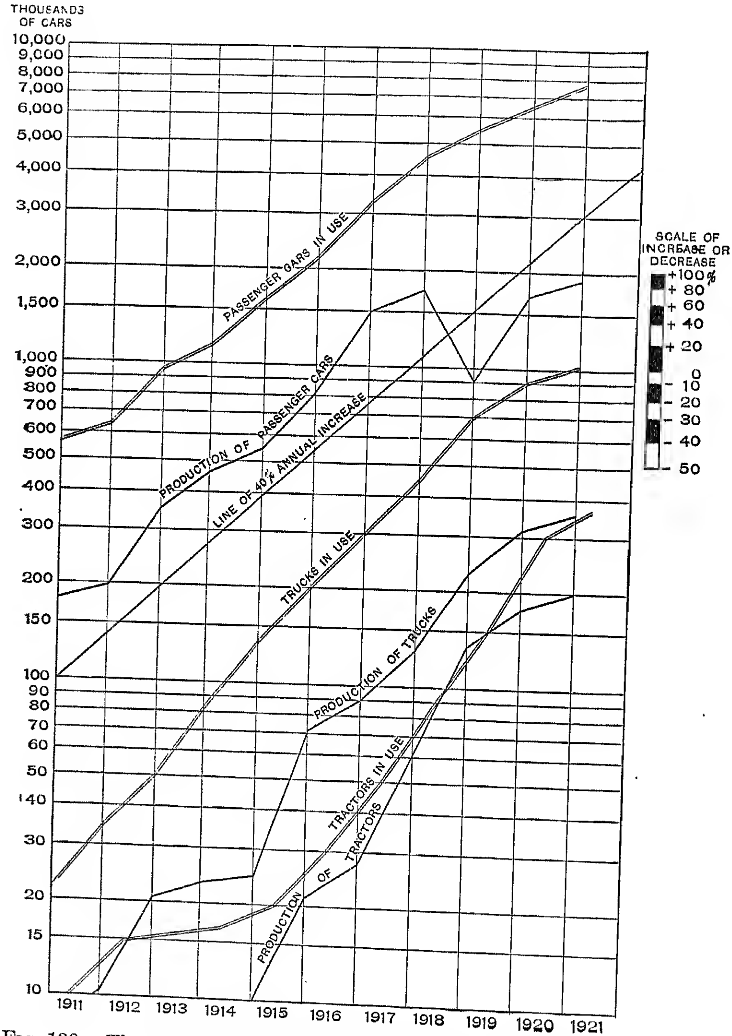


Fig. 130.—The growth of automotive transportation by years, 1910–1920.

Future Demands of Automotive Transportation.—The 1910–1920 rate of growth of automotive transportation which approximated 40 per cent per year represents a rapidity of growth that can not be expected to continue unabated; a careful inspection of Fig. 130, indeed, reveals the tendency of the trend lines to modify their slopes

toward the end of the decade represented. A careful analysis of the factors entering into the growth of automotive transportation, however, suggests that while the exuberant expansion characteristic of the past decade will undoubtedly become more temperate, a substantial and continuous growth may be expected, barring the inability of the petroleum industry to maintain a supply of motor-fuel and lubricants at a favorable price. Reference to Fig. 130 will bring out the fact that as the rate of expansion of passenger cars begins to taper off, the growth of motor trucks comes forward as a supporting factor; and as the expansion in this field begins to moderate, the growth of tractors comes into prominence.

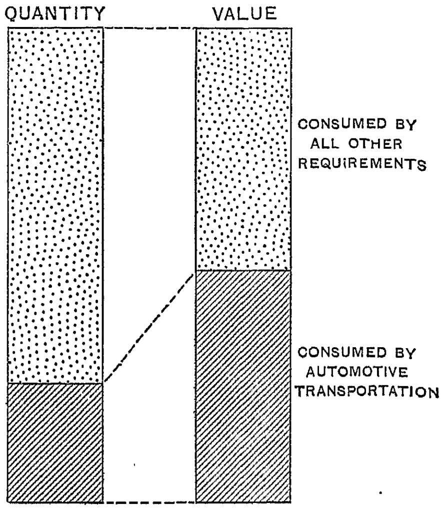


FIG. 131.—Quantity and value of petroleum products consumed by automotive transportation compared with the consumption by all other requirements in 1920.

TABLE 115.—PRODUCTION OF CARS, TRUCKS AND TRACTORS IN THE UNITED STATES BY YEARS, 1910–1920

(In thousands)

Year	Passenger Cars *	Trucks *	Tractors
1910	181	6	4.5
1911	199	11	7.4
1912	356	22	11.4
1913	462	24	7.4
1914	544	25	10.4
1915	819	74	22
1916	1494	90	28
1917	1741	128	63
1918	926	227	135
1919	1658	316	175
1920	1883	322	200

* Data from National Automobile Chamber of Commerce.

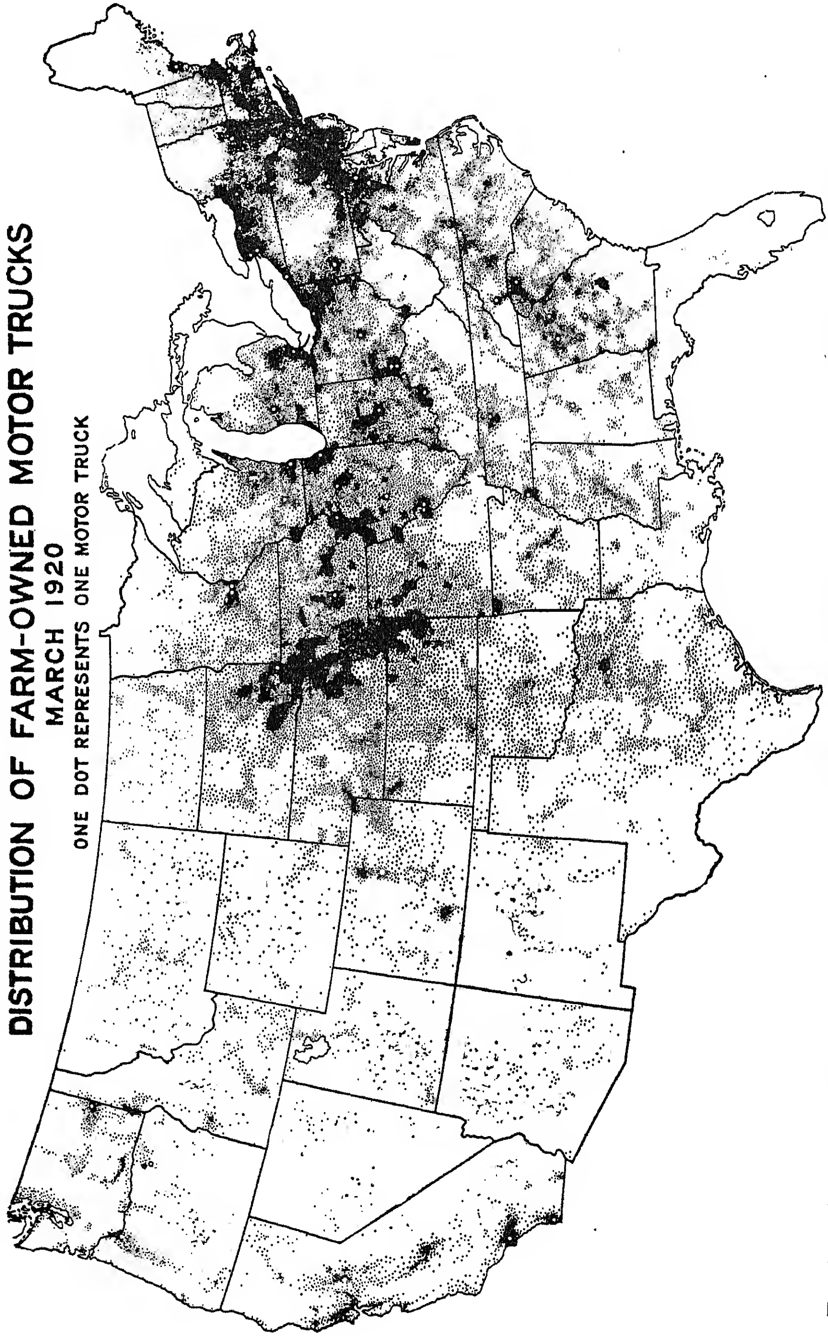


Fig. 132.—Distribution of farm-owned motor trucks in March, 1920. Map by Office of Farm Management, U. S. Department of Agriculture.

The approach of passenger cars to a number representing the saturation point of the country does not therefore mean a limitation to the whole field of automotive transportation. The growth of truck haulage has no such saturation point. With a bountiful and cheap supply of fuel the motor truck can expand to a further degree, finally enlarging its scope of activity from the field which characterizes it at the present to a point of coordination with railway transportation which will make it an integral part of that countrywide system.

Tractors likewise occupy a field which is in its infancy. Mechanical tillage and mechanical work on the farm represent the only solution in sight for the growing food requirements of a large population and for the steady migration of labor from rural districts to industrial centers. The aeroplane also is a type of automotive transportation whose future would appear to be important should no limitation of fuel supply intervene.

On the whole, the future demands of automotive transportation appear to be insatiable. The requirements of this field present to the oil industry an opportunity and an obligation which cannot be exaggerated. Automotive demands will either make the oil industry greater than it is at present, or they will place a burden upon the oil industry which it cannot support.

Effect of Automotive Requirements upon Oil Products.—Already the rapid growth of automotive requirements has had a far-reaching effect upon the character and volume of products turned out by the oil industry. Gasoline has been changed from a minor to a major product. Kerosene has been raised in price, and gas oil is in course of diversion from the open market. Fuel oil has been seriously cut into, and the supply of lubricating oils, especially those of heavier body, has been heavily burdened. These may be regarded as the initial effects that automotive transportation may be expected to exert in growing degree upon the oil industry. It may be worth while to review these consequences in somewhat greater detail.

Effect upon Gasoline.—Once a reject in connection with the manufacture of kerosene, gasoline in the aggregate is now the most profitable product turned out by the oil industry. In the past ten years its output has grown from a quantity representing scarcely 6 per cent of the crude oil consumed in the United States to a present volume which represents 22 per cent. The mounting demand for gasoline has not only stimulated the output of crude petroleum, but has also dictated refinery expansion and changes in refinery technique until now it not only involves practically all of the natural gasoline extracted from the crude petroleum, but draws upon outside sources

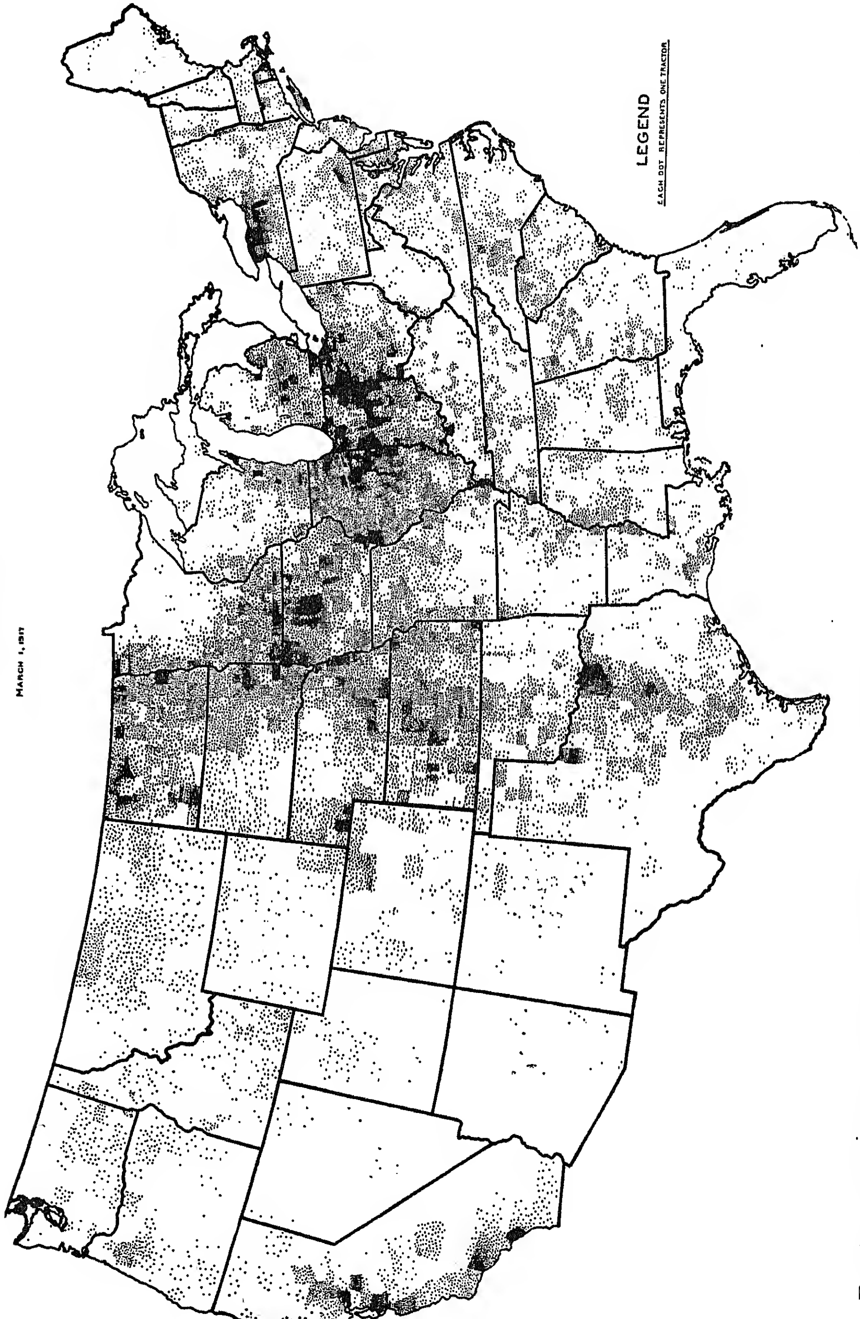


Fig. 133.—Distribution of tractors on March 1, 1917. Map by Office of Farm Management, U. S. Department of Agriculture.

of gasoline such as that won from natural gas. In the past few years also, cracking processes of distillation have been developed and changes in the character of the gasoline supply to the inclusion of material once marketed as light kerosene have come into play. In addition blends of gasoline and naphtha with benzol and alcohol are coming on the market, thus indicating the opportunity for increments to the gasoline supply from extraneous chemical sources. All of these factors are the direct resultant of the growth of automotive transportation. Without a rapidly increasing demand for gasoline, these changes would not have become necessary and would not have appeared.

Effect upon Kerosene.—Once the major product of the oil industry both in volume and value, kerosene has been subordinated to a secondary position. In spite of a growing consumption of crude petroleum the output of kerosene has remained nearly stationary, the potential increase going instead into the production of gasoline. The supply of kerosene also, once largely confined to lighting and heating, is now undergoing encroachment by the internal combustion engine. Considerable quantities of kerosene are used in stationary engines, boats and tractors. The domestic market for kerosene has thus come largely to lose its former seasonal character. The peak of the kerosene demand has been lost in the leveling effect of automotive requirements.

Effect upon Gas and Fuel Oil.—The mounting requirements for gasoline have forced the expansion of cracking processes of distillation using gas oil to such an extent that the supply of this product, once catering dominantly to the manufacture of city gas, has become insufficient for meeting the combined demand and a serious shortage of gas oil is under development. This latent stringency may be expected to increase until the gas industry is forced to adapt its practice either to get along without gas oil, or as a temporary expedient to make use of the heavier varieties of fuel oil. A continued growth of cracking is to be expected, and this expansion will not only quickly preempt the available gas oil but will gradually encroach upon the whole fuel oil supply to such an extent as to curtail many of the industrial and transportation demands now dependent upon this product.

Effect upon Lubricants.—The requirements of automotive transportation have injected a new and rapidly growing demand into the country's output of lubricating oils. While crude petroleum is produced in excess of lubricating needs, expansion in the production of lubricating oils is predicated upon extensive changes in refinery equipment. During the past few years, the addition of automotive

requirements to the normal industrial demand has expanded the need for lubricants beyond the capacity of the types of crudes formerly regarded as essential to the manufacture of the best products, with the result that growing emphasis is falling upon the asphaltic crudes which in the early days of refining were not regarded as suitable raw material for the fabrication of lubricants. During the early part of 1920, the rapid growth of the automotive demand resulted in a shortage of the heavier-bodied lubricating oils such as enter significantly into the make-up of motor-oils. These effects in the long run may be expected to continue and to have still further influence upon refinery technique and upon trade practice in respect to compounding the oils employed.

Creation of a Motor-fuel Problem.—The growth of automotive requirements in excess of a corresponding rate of expansion on the part of the oil industry has created a maladjustment between the motor-fuel supply and the average automotive equipment for handling the fuel. In an attempt to maintain sufficient gasoline, the character of the gasoline has been permitted to change until now it is somewhat less adapted to the engine than was once the case. This lack of balance between engine and fuel has created a problem which is receiving the active attention of the automotive industry and constitutes a field of growing importance. It is rapidly coming to be evident that increasing difficulty will be met in maintaining the supply of motor-fuel without a greater degree of correlation between the fuel and the engine than has yet been attained. The accomplishment of a parallel development of fuel and engine to the maximum easement of the fuel supply constitutes in simplest terms the motor-fuel problem.

Creation of a Dilution Problem.—The rapid growth of automotive requirements in respect to gasoline, entailing a physical change in the character of the latter, has had a secondary effect upon the lubricating oil used in the internal combustion engine. The heavy ends of the gasoline, increasing in quantity as the volatility of the commercial supply of gasoline decreased, have tended more and more to pass through the automotive apparatus incompletely burned and to dilute the crank-case oil, with serious effects upon the efficiency and the life of the engine. This outcome has brought sharply to the fore the necessity of regarding motor-oil and motor-fuel as complementary products, each to be adapted to the character of the other, and the two to be coordinated with the engine type. This matter offers an opportunity for constructive work of importance.

Creation of a Peak-load Problem.—The growing demand for gasoline has been complicated by the seasonal character of the

requirements. As is well known, the quantity of gasoline needed for the months of July and August is roughly twice the requirement of a similar period during the winter. With the growth of the gasoline demand from year to year the peak load has become more and more accentuated. A shortage in supply will make its first appearance as a stress at the peak season. Under such conditions, the free operation of the law of supply and demand will dictate price advances for the purpose of allocating the inadequate supply. And gasoline touches the interests of so many individuals that sharp price increases accompanying a shortage are likely to bring on popular disapproval and governmental investigation, with the possibility of official restrictions and regulations. Hence counter-methods of cooperative allocation in the place of price allocation may come under consideration, in an attempt to avoid the results of governmental action.

The Oil Industry Becoming a Transportation Industry.—The outstanding characteristic of the oil industry is its rapid and inevitable drift toward the status of a transportation industry, with all the public service obligations and restrictions that this term implies. The problem faced by the oil industry in this respect is a difficult one. The industry has inherently assumed responsibility for maintaining the supply of motor-fuel. This supply in all probability, however, cannot be maintained in requisite degree, so insatiable are the demands of automotive transportation. As a result, a motor-fuel shortage and a consequent price reaction become an ultimate eventuality, with all the possibilities that may grow out of that circumstance.

CHAPTER XX

THE ECONOMIC SIGNIFICANCE OF CRACKING

Nature of Cracking.—It has long been known that when subjected to high temperatures the heavier components of crude petroleum break down or crack into lighter compounds. Thus, distillation processes, early in the development of oil refining, were so adjusted that the hot vapors fell back into the still, whereupon some decomposition would ensue, leading to an enlarged output of kerosene and gasoline. Such processes, however, increased the refinery losses and were so destructive of the lubricating components that they were found inexpedient in refineries intent upon producing lubricating oils in maximum output and of superior quality.

The desire to offset the lessened yield of gasoline and kerosene incidental to lubricating output was one of the incentives that led to the development of independent cracking processes which could be applied *after* the initial separation of the components had taken place. This is the type of cracking that has outstanding significance under present conditions. Cracking during the initial distillation, though still widespread in refinery practice, is due to pass as refinery equipment is converted more and more to lubricating plants making a full extraction of values. At the same time cracking as an independent process, applied to one or more of the distillates obtained from the initial process of distillation, is on the increase stimulated by the growing demands for gasoline.

Cracking Processes.—A large number of cracking processes have been devised, but few have attained commercial success; and only one, the Burton process, controlled by the Standard Oil Company of Indiana, has thus far made large contributions to the gasoline supply. The principles of the important processes are roughly the same—distillate fuel oil of a not too heavy character (gas oil) is subjected to special treatment under the influence of heat and pressure by means of which it is broken down or cracked into gasoline and a residual fuel oil, with the incidental formation of some carbon.

While high efficiency is often claimed for cracking processes, the current commercial practice yields gasoline on an average of only about 30 to 40 per cent of the original material subjected to the

process. Thus 100 gallons of gas oil ordinarily produce 30 to 40 gallons of gasoline, the remainder being left in the form of residuum available as fuel, and coke which must be removed periodically from the apparatus at considerable expense.

The cost of cracking is not publicly known, but the inference may be drawn from such information as is available that gas oil may be profitably cracked so long as its market price does not exceed roughly two-fifths to one-half the price of gasoline. Thus, with gasoline selling at 30 cents, it would be profitable to crack gas oil if the latter does not bring over 12 to 15 cents for other purposes. For the city-gas industry to secure a supply of gas oil, for example, it must compete with the cost relation just noted and be prepared to pay more than the value of the oil as a raw material for cracking. But effective competition in this direction would curtail the output of gasoline and result in a rising price for the latter which again would place the price of gas oil on a higher level. The mere fact that motor-fuel represents an economic requirement of higher rank than the demand for gas oil for purposes of enriching city-gas, indicates that cracking will not be effectively retarded by the claims of the gas industry upon this raw material.

Raw Material for Cracking.—Cracking is successfully conducted in practice by utilizing only the lighter varieties of distillate fuel oil (gas oil) as raw material. The reason for this preference is that as fuel oil increases in density, or weight, the ratio of carbon to hydrogen in its components also becomes greater, and larger losses and relatively smaller yields are obtained in proportion as the raw material is richer in carbon. Thus as cracking is applied to successively denser types of fuel oil a critical point is reached at which cracking becomes commercially impracticable, irrespective of the efficiency of the process; and beyond which the manufacture of gasoline from such raw material can be accomplished only by a process of hydrogenation, or hydrogen-adding. The position of such a point is hard to determine accurately, especially as it may be shifted slightly by technical and economic changes in the cracking situation; but it is a fair assumption that it divides the country's supply of fuel oil into two portions, of which the larger includes the heavy fuel oils unsuited for cracking.

The heavier varieties of fuel oil (including residuum), which far outweigh in volume the lighter distillate fuel oils, have not therefore lent themselves to effective or profitable cracking. Some additions to the country's supply of light distillate fuel oil will come through changes in refinery practice, especially as skimming plants develop into complete-run refineries; but significant additions on this score

cannot arrive rapidly. On the whole, the rigorous requirements of cracking processes in respect to raw material put a serious brake upon the rapidity with which the output of cracked gasoline can increase, and set an ultimate limit far short of the point at which the total fuel-oil supply of the country would be involved in the process. Under present practice, it will be scarcely possible, roughly speaking, for cracking to involve more than half of the fuel-oil supply and to yield cracked gasoline in excess of 25 per cent of the total quantity of fuel oil produced.

It is apparent, then, that as the output of cracked gasoline increases, more and more of the lighter varieties of fuel oil will be diverted from their present uses until only the heavy fuel oils will be left to meet the normal commercial demands for this product.

Residuum from Cracking.—A significant factor in the growth of cracking is found in the high proportion of the raw material which is not converted into gasoline and hence is thrown back into the fuel-oil supply as an uncrackable residuum. The volume of this residuum increases in direct proportion to the quantity of cracked gasoline produced, and hence as cracking eats into the fuel-oil supply on the one hand, a greater volume of residuum accumulates on the other; therefore the fuel-oil reserve of the country is encroached upon by cracking at more than double the rate ordinarily taken into account. Fig. 135 illustrates this point and indicates how quickly, irrespective of the quantity of fuel oil available, the potentiality of cracking may be realized.

Relation of Cracking to the Gasoline Supply.—The demand for gasoline is growing faster than the supply of crude petroleum, and since 1917 the quantity of gasoline produced in this country has exceeded by a widening margin the quantity of *natural* gasoline contained in the crude petroleum consumed. (See Fig. 134.) Although casing-head gasoline and a change in the average quality of commercial gasoline to include some of the lighter kerosene cuts have augmented the supply of gasoline, the main increment to the normal quantity is now the contribution from cracking stills. A rough view of the growth of the various components entering into the gasoline supply is shown in Fig. 52, page 116.

Natural Gasoline.—The potential supply of natural gasoline has been calculated from the character and output of the crude petroleum produced in the various states and imported, and the results are plotted in Fig. 134 against the actual production of gasoline. The chart shows clearly that up to 1917 more natural gasoline was present in the crude petroleum consumed than was necessary to meet gasoline requirements, whereas after that year supplementary sources of

gasoline were necessary to fill the demand. The chart also brings out the important part played by the high-gasoline crudes of the North Texas field in 1919–1920. Projecting forward the data shown, especially in the light of the growing importance of low-gasoline

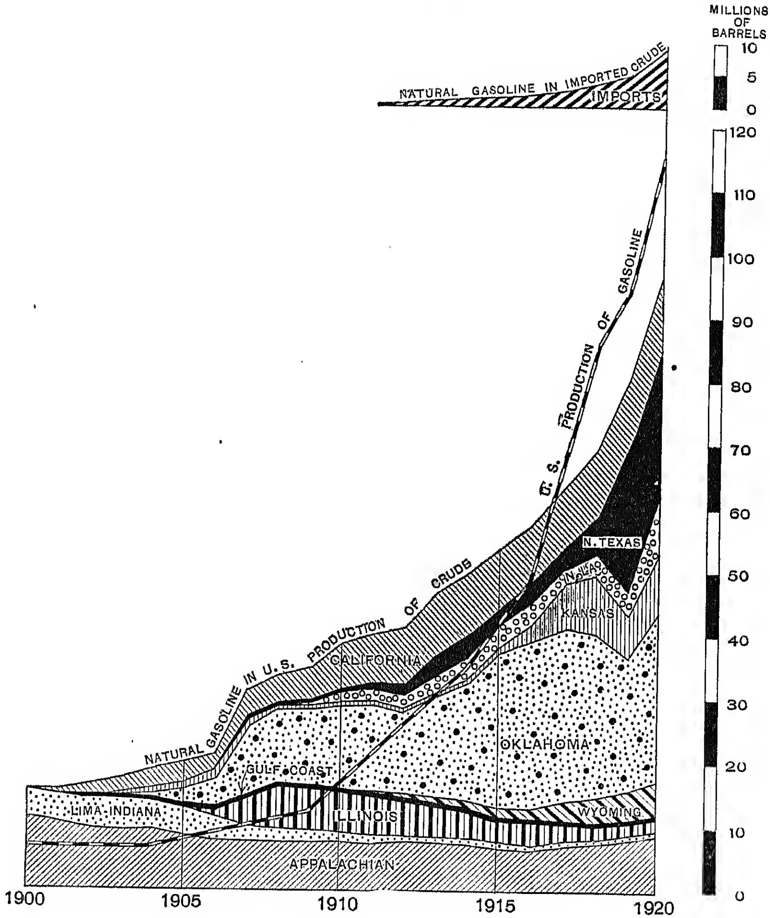


FIG. 134.—Chart showing the natural-gasoline content of the crude petroleum annually produced in the United States by fields and imported during the period, 1900–1920.

crudes, it would appear that the available natural gasoline will show a slowing rate of increase in the face of an accelerating demand. This tendency will increase the burden falling upon cracking and create a gasoline shortage in the failure of cracking to expand with sufficient rapidity. Fig. 134 will repay careful consideration, as it dissects and measures the trend of the component parts of the largest contributor to the gasoline supply.

Casing-head Gasoline.—A significant production of a highly volatile gasoline, called casing-head gasoline, is won from natural gas. This relatively new source of supply has made important contributions, approximating in 1920 about one-tenth of the total output of gasoline, and having an added importance as a blending agent facilitating the employment of light kerosene as motor-fuel. As to the future, a careful appraisal of the casing-head gasoline industry indicates that while in absolute terms the output of this product will probably increase, its ratio to the total production of gasoline of all types cannot be expected to become greater. Hence, casing-head gasoline has already exerted its maximum effect upon the gasoline situation, and may be accredited with no added importance in appraising the broad developments ahead.

End-point of Gasoline.—Since 1915, especially, the volatility of gasoline the country over, while showing minor fluctuations, has steadily decreased. Expressed in terms of the boiling point of the heaviest fraction—technically called the end-point—this statement is equivalent to saying that the end-point of gasoline since 1915 has notably risen. This again is equal to stating that a considerable quantity of light kerosene according to 1915 standards now goes into the supply of gasoline, constituting the high boiling-point fractions, or "heavy ends," of the latter and causing the present high end-point. The average end-point of the country's supply of gasoline, according to recent motor-gasoline surveys conducted by the Bureau of Mines, was 417° F. in April, 1919; 427° F. in January, 1920; 456° F. in July, 1920; and 429° F. in January, 1921.

The advance in end-point of gasoline is an indication that the demand for this product is exceeding the combined efforts of natural gasoline, casing-head gasoline, and cracked gasoline to meet requirements. The only handicap to a continued advance in end-point is the inability of existing internal combustion engines to utilize efficiently the heavy portions of such products. A significant tendency toward engine adaptations in this direction, however, is coming into being; and the gasoline situation will be considerably influenced by the extent and rapidity with which automotive equipment becomes capable of handling heavier and less volatile motor-fuels.

The course of automotive developments, in consequence, will have a bearing upon cracking; and should automotive equipment come to a point of independence in respect to the volatility of the fuel which it consumes, cracking will no longer be necessary and will decline. The possibility of this eventuality must be borne in mind in appraising the future of cracking.

Appraisal of the Future.—An attempt to reduce to a quantitative basis the line of reasoning given above is shown in Fig. 135, which traces the factors involved through the past ten years on the basis of

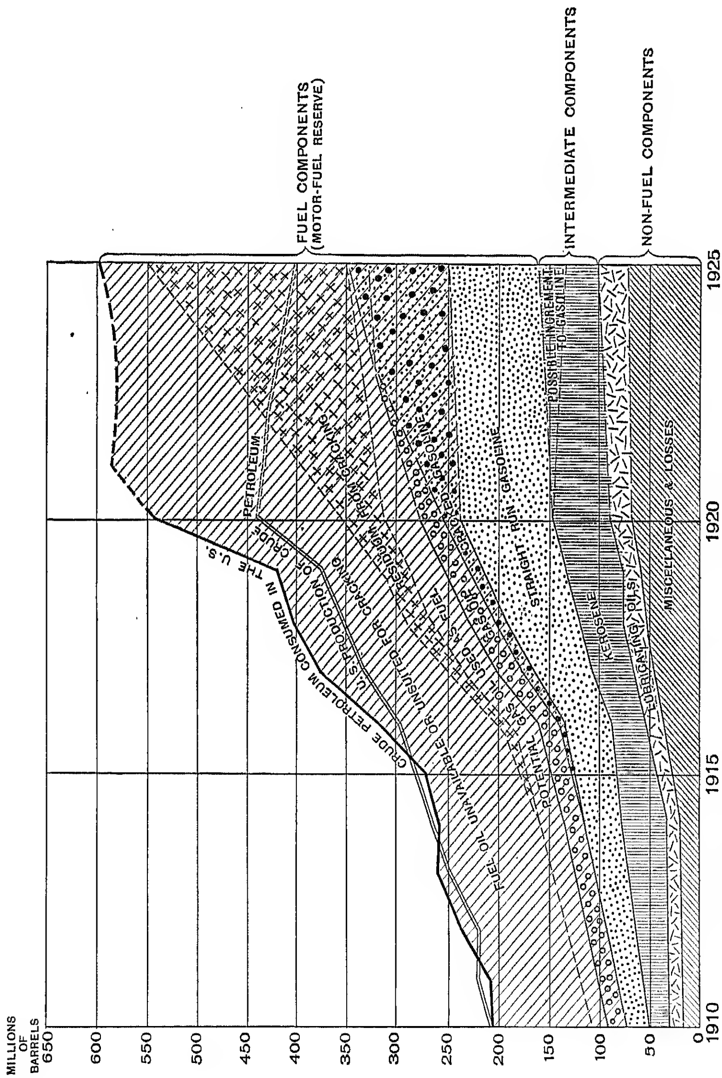


Fig. 135.—Chart showing the economic status of cracking and the outlook for gasoline, gas oil, and fuel oil.

actual statistics and projects the probable course of events to the end of 1925.

Fig. 135 shows the consumption of crude petroleum in the United States during the period 1910–1925 (estimated of course for 1921–1925) divided broadly into the fuel and non-fuel components, kero-

sene being left as intermediate or neutral ground which may swing either way. The projected course of crude consumption is of course hypothetical, although based on a careful analysis of the situation; but the point should be emphasized that the validity of the chart *does not* depend upon the accuracy of the projected portion of the crude consumption curve. Large variations in the latter may be seen to have a greatly minimized effect upon any component shown.

The chart represents fuel oil as a motor-fuel reserve upon which cracking is rapidly encroaching. This invasion will probably remove gas oil from the open market before the end of 1923, while the supply of potential gas oil will probably run out (being entirely consumed for cracking) by the end of 1925. If this reasoning is essentially correct—and it will merely be modified, not invalidated, by unforeseen developments in supply—cracking would reach its maximum *rate* of expansion in five years, slowing down after 1925 to a rate of growth parallel with the increase or decrease in the quantity of crude petroleum made available for consumption. Such is essentially the outside attainment that may be expected from cracking in the next five years; as a matter of fact, the growth of cracking is likely to be less than the maximum indicated on the chart, perhaps approximating the dotted lines passing through the area marked "cracked gasoline."

The question therefore arises as to whether cracking can sustain the supply of motor-fuel in sufficient volume to support the mounting requirements of automotive transportation. The conclusion that seems indicated by the analysis given is that the supply may be maintained over a few years, but shortly the limitations to cracking will come into effect, and cracking unaided by other expedients will begin to prove inadequate. In this event, the internal combustion engine will be gradually forced to fall back upon heavier, less volatile fuels than gasoline, which will set up a counter demand for the light fuel oils and other distillates for admixture directly with gasoline, and thus cut into the raw material for cracking at the same time that cracking is rendered progressively unnecessary.

CHAPTER XXI

COMPOSITE MOTOR-FUELS

In recent years considerable attention in the automotive field has been directed to the relation existing between the internal combustion engine and its fuel. The rapid rise of automotive transportation has led to a country-wide change in the volatility of gasoline, which has attracted no end of interest and raised the problem of better fitting the fuel to the engine, or vice versa, or else striking a compromise adjustment between the two.[1]

As the matter is shaping up now, there are three avenues through which this adjustment is tending to come about:

(1) The production of a growing quantity of synthetic gasoline from the heavier oils, through the so-called cracking processes of distillation.

(2) Adaptations on the part of the engine to accommodate the efficient utilization of less volatile gasolines and heavier oils.

(3) The development of composite fuels or blends, which permit the enlargement and possibly the improvement of the fuel supply, through additions of material not suitable or sufficiently bountiful alone to be of consequence.

The future of any one of these three expedients for furthering the advance of automotive transportation depends upon the course of development in respect to the other two, and the final outcome will be the resultant of factors which cannot be wholly appraised in advance. Not the least of these is the extent to which the whole matter is brought under scientific control by far-sighted and constructive efforts on the part of the fuel and automotive industries acting in common.

Composite fuels are by no means a new element in the fuel situation, even in the United States. Indeed, much of the gasoline marketed in this country to-day is composed of straight-refinery gasoline blended with gasoline made in pressure stills, or with casing-head gaso-

[1] Pogue, Composite Fuels, Society of Automotive Engineers, January 7, 1920.

line recovered from natural gas, together with petroleum distillates that were formerly sold as naphtha or kerosene; and even gasolines are being modified through the addition of benzol. Casing-head blends alone have succeeded in adding about 10 per cent to our total supply of engine fuel. Composite fuels, in which not only distillates of petroleum origin but benzol, coal-tar oils, alcohol and even other chemical products play a part, have of course been long in use in Europe, and some of these met with considerable expansion during the war, especially in Germany. In the past few years, fuel blends containing benzol or alcohol have also come into qualitative, if not quantitative, prominence in the United States, thus drawing attention to the possibilities of their future importance in this country.

Source of Composite Fuels.—The resources in sight from which the components of composite fuels may be drawn are mainly three in number:

(1) Crude petroleum (ultimately including shale oil).
(2) Bituminous coals, which are capable of yielding tar oils, benzol products and other hydrocarbons when subjected to by-product distillation.
(3) Organic products rich in sugars, starches or cellulose, especially waste products of organic origin, from which oxygenated hydrocarbons such as alcohols and ethers can be manufactured, chiefly through the aid of bacterial fermentation.

As regards the quantity of raw material available, the United States is bountifully endowed in all three respects. Since, however, an extensive and highly organized industrial agency of fabrication and distribution must stand between these resources and the utilization of their fuel potentialities for automotive power, the development of composite fuels becomes dependent not only upon the conditions controlling the growth of the oil-refining industry, the coal-refining industry, and a group of activities which may be termed the fermentation industry, but also upon the interplay between these interrelated activities.

The oil-refining industry is the largest, most firmly established and highly developed of the three, and its capacity and industrial ability may briefly be dismissed as being sufficiently in mind. This industry turns out four products of major importance, gasoline, kerosene, fuel oil and lubricating oil, not to mention by-products; and its output of gasoline, in consequence, is intimately tied in with the manufacture of joint-products demanded by needs scarcely less pressing than automotive transportation. Thus, gasoline has

become a commodity which must be produced, if the market for other oil products is to be supplied; while the oil industry in addition has established country-wide machinery for distribution. These economic facts have a direct bearing upon the manner in which composite fuels can be expected to develop; they make it probable that composite fuels, if found desirable, will ultimately be purveyed dominantly by the oil industry rather than by outside activities, under whatever auspices the initial developments take place and without any reference to matters of financial control.

Coal Products.—The coal-refining industry has thus far been slow of development in the United States. To date it has succeeded in involving only about one-twelfth of the bituminous coal brought into use, approximately eleven-twelfths being still consumed in the raw state; the coke industry and the artificial-gas industry are responsible for the advance noted. The production of benzol and related hydrocarbons is mainly dependent upon the progress attained in coal refining.

Up to the present, most of this progress has taken place in the coke industry, where by-product practice is gradually superseding the so-called beehive process, in which benzol and other by-products are not recovered; benzol is now being produced in connection with about half of the coke manufactured in this country. In 1920 the output of benzol from this source was 80 million gallons. With by-product practice throughout the coke industry, the output would have been but doubled, around 3 per cent of the quantity of gasoline produced. The coke industry, therefore, can at best be expected to furnish a quantity of liquid fuel wholly inadequate to have broad significance, except in so far as it may be used as a blending agent to give desirable qualities to other liquid fuels obtainable in larger quantities.

The artificial-gas industry was responsible in 1918 for the production of about 4 million gallons of benzol, recovered from gas plants operating with by-product recovery. The entire artificial-gas industry, however, consumes less than 2 per cent of the country's output of bituminous coal, and as long as this activity retains its present stationary position the quantity of engine fuel to be expected from this source is practically negligible. There is a possibility, however, that the future will see the upgrowth of municipal fuel plants and centralized power stations, operating with by-product recovery, which will give a new source of benzol of greater significance than the coke industry in its entirety. But such developments must of necessity be slow; and should benzol eventually be extracted from the bulk of our bituminous coal, it is evident that, on a

basis of 2 to 3 gallons per ton, the supply will even then fall far short of a dominant position as a source of automotive power.

During the past few years, investigations by Kettering and Midgely in the laboratories of the General Motors Research Corporation on the chemical changes taking place during combustion, have opened up new and interesting possibilities in the direction of increasing the efficiency of the petroleum motor-fuels by the addition of small quantities of appropriate chemical substances. These investigations have indicated that the tendency of the engine to "knock" when run on fuels of low volatility arises from the formation of secondary, detonatable compounds which decompose with explosive violence and cause an abnormal rise in pressure.[1] This tendency stands in the way of further raising the end-point of gasoline without at the same time lowering the compression of the engine, which blocks the enlargement of our fuel supply not only by rendering deeper cuts into the crude ineffective, but also by preventing the added fuel economy that could be attained with engines of higher compression. It has been shown, however, that the addition to the fuel of small percentages of aniline—a nitrated benzol—leads to even combustion without detonation, and therefore not only improves the performance of present-day high-end-point fuels, but opens the possibilities of still further raising the end-point and at the same time gaining additional efficiency by increasing the engine compression.

This work is of the first importance, both by virtue of what it is actually accomplishing, and in respect to what it suggests as to the possibilities of fabricating directly into the fuel, during the process of refining, the properties which would lead to a more efficient utilization in present engines and eventually to the development of more efficient engine types.

Alcohol.—The fermentation industry, notably the branch having to do with the manufacture of industrial alcohol, was strongly stimulated by the war, and industrial machinery was developed for the production of considerable alcohol for fuel purposes. The arrival of prohibition also freed a large equipment from other duties, which might be turned in part to a similar purpose. There are serious handicaps of a sentimental nature, however, which tend to bind the manufacture of industrial alcohol with restrictions harmful to progress. Besides which, the industrial depression of 1920–1921 has retarded advance in this field.

[1] C. F. Kettering, More Efficient Utilization of Fuel, Jour. Soc. Aut. Eng., April, 1919; Consumption, The Automotive Industry, American Petroleum Institute, Bull. 132, December 10, 1920. The Midgley Gas Engine Indicator, Dayton, 1920.

Alcohol alone can be used to advantage only in engines especially adapted to this fuel, but various mixtures of alcohol, benzol, gasoline or other petroleum distillates, and other materials have given promising results. It is of great significance from an economic standpoint that alcohol, benzol and the lighter petroleum distillates such as gasoline and kerosene can readily be rendered miscible. It is probable that alcohol, like benzol, will not come into widespread use as a single fuel, but has a broad significance, for the present at least, only as a blending agent in connection with liquid fuels obtainable in larger quantities.

The quantity of alcohol which will be produced in this country in the immediate future is much more difficult to foresee than in the case of benzol. The United States in 1916, 1917, and 1918, turned out about 50 million gallons of denatured alcohol each year, having increased from an output of 14 millions in 1915 under the stimulus of munitions requirements. Much of the industrial alcohol under manufacture to-day is made from sugar molasses and waste sulphite liquor; while garbage, fruit wastes, ethylene from coal-distillation plants, and other materials may be counted as supplementary resources. Considerable interest has been aroused in some quarters by the possibility of installing individual manufactories on farms and in various centers, making use of plant wastes; but it is questionable whether an extensive attainment of this kind is practicable and moreover the widespread production of alcohol would set up competition for products needed directly or indirectly for food. While the ultimate alcohol capacity of the country cannot be closely measured, the conclusion seems warranted that for some time to come the available supply will bear a close quantitative analogy to benzol, the two combined bulking small when compared with engine-fuel requirements which already approach 5 billion gallons per year.

On the whole, therefore, it would appear that benzol and alcohol hold somewhat analogous positions in respect to the supply of motor-fuel. Neither can be produced in sufficient quantities in the near future to replace gasoline; both have interesting possibilities in the direction of improving the character of the fuel supply. This whole field is undeveloped and stands in need of more research attention than has been accorded it.

Conclusion.—If found to fulfil their initial promise of advantage, composite fuels can be developed by the oil industry, or in a more limited manner by outside agencies; but they can more readily be produced on a large scale by the oil industry because of its control of working channels of distribution. The possibilities of improving the supply of gasoline by chemical means are of distinct promise, and

consequently there may come into evidence a steady trend toward a fuel supply of petroleum origin carrying small quantities of other materials which will facilitate utilization in present types of engines and at the same time free the development of future engines from the present limitations of low compression.

CHAPTER XXII

THE MOTOR-FUEL PROBLEM

One of the most remarkable and significant developments of modern times is the sudden and spectacular rise of automotive transportation. In scarcely more than two decades, the whole color of existence has been changed by the automobile, the motor-truck, the tractor and the aircraft, which have come to be so numerous and commonplace as to be seen on every hand. Almost overnight, transportation has been freed from limitations of relative inflexibility, and a mobile and speedy agency of carriage has appeared on the scene to open to transportation the second and third dimensions.

So rapid has been the growth of the automotive industry and of the consequent demand for motor-fuel, that the ability of the fuel supply to keep pace has come in question. The supply of motor-fuel, indeed, is already showing the effects of the tremendous demand bearing down upon it; and there arises, in consequence, a motor-fuel problem which is commanding the serious attention of all the interests at stake. Since a fuel stringency, or undue advance in price, would prove a retarding factor in the progress of automotive transportation, the prospect is one of vital concern not only to the industrial activities involved, but to the general public as well.

The factors involved in this problem are the demand for motor-fuel and the adaptability of the internal combustion engine, on the one hand; and the supply of crude petroleum, the motor-fuel producing capacity of this material, the supplementary fuel materials in sight, and the possibilities of advantageous chemical change in the fuel supply, on the other. Out of the interplay of these factors will come developments, focused in the price of motor-fuel, that will determine the future of automotive transportation.[1]

The Demand for Motor-fuel.—The demand for gasoline has been increasing of recent years at an imposing rate. The nature of this expansion has been described in Chapter XIX. (See also Fig. 57, p. 124.) The projection of this demand into the future leads to interesting conclusions.

[1] See J. E. Pogue, An Interpretation of the Engine-fuel Problem, Society of Automotive Engineers, February, 1919.

The probable number of motor-vehicles which will be required by automotive transportation in the years immediately ahead, if the demand is not curtailed by an inadequate supply of fuel or an undue advance in its price, has been calculated on the basis of the trend of population increase and the assumption that the maximum ratio of vehicles to population as found to-day in the most prosperous sections will become characteristic of the entire country. Calculations for passenger cars and trucks, made on this basis, by the Commercial Research Department of the Franklin Automobile Company are shown in graphic form in Fig. 136. This projection for cars and trucks, together with the prospective number of tractors on an assumed increase of 200,000 a year (the number produced in 1920), is converted into gasoline and crude petroleum in Table 116, on the basis of the present fuel consumption per unit and a conversion factor of 25 per cent representative of the proportion of gasoline obtained from crude petroleum under present conditions.

TABLE 116.—FUTURE DEMAND FOR GASOLINE IN THE UNITED STATES IN 1925, 1930, 1935 AND 1940, BASED ON PRESENT CONDITIONS OF FUEL SUPPLY AND FUTURE NUMBER OF MOTOR-VEHICLES AS PROJECTED BY FRANKLIN AUTOMOBILE CO.

(In millions of barrels)

Year	Gasoline Required by —			Gasoline, Total Requirements	Equivalent in Crude Petroleum on Basis of 25 Per Cent Conversion Factor
	Passenger Cars	Trucks	Tractors		
1925	80	120	16	216	864
1930	96	216	28	340	1360
1935	112	312	40	464	1856
1940	120	360	52	532	2128

While the figures shown are admittedly excessive and to be considerably discounted, especially in regard to trucks, they nevertheless point to a future motor-fuel demand of stupendous proportions. With an unmined reserve of crude petroleum appraised at 6 billion barrels, having an estimated gasoline content of only 1 billion barrels, the gasoline demand as shown would exhaust the entire domestic reserve by 1926, and projected further would call for an annual share in the world's output of crude petroleum running upward of 1300 million barrels by 1930 and exceeding 2 billion barrels by 1940. It is evident that if such a demand, even halved, is to be met by gasoline on the basis of present engine types and performance, the oil industry must expand to proportions vastly

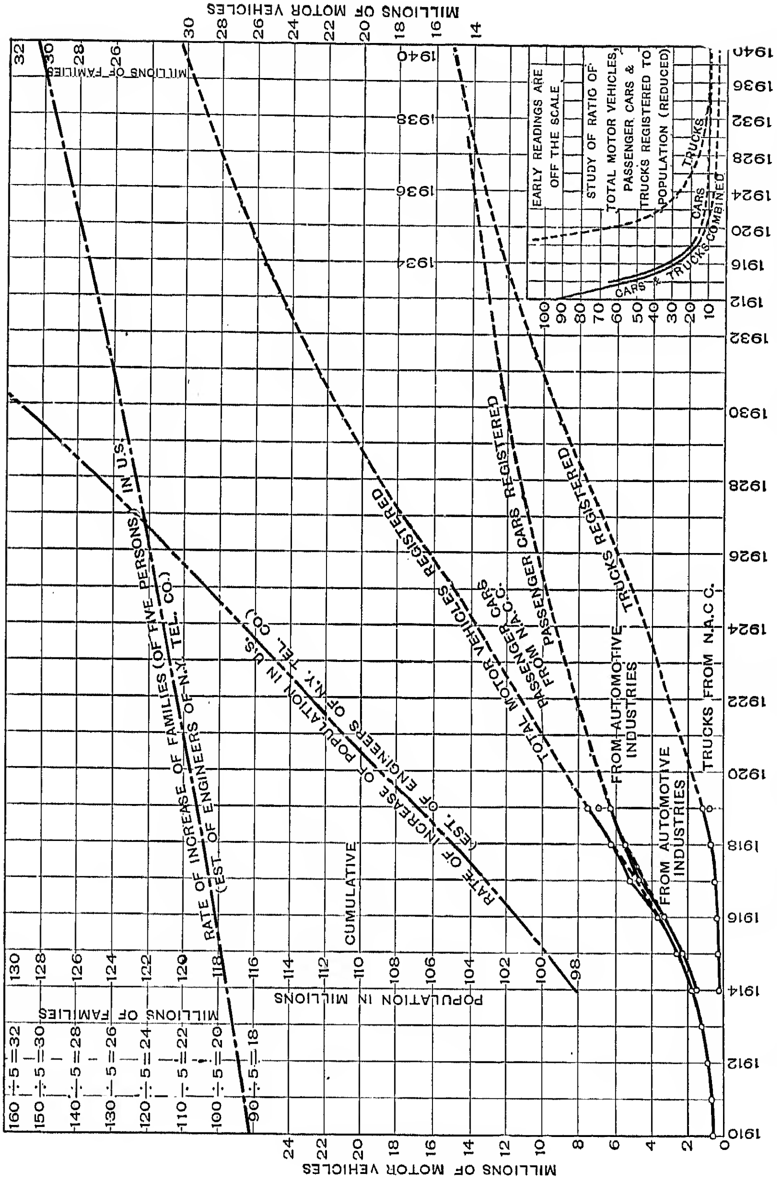


Fig. 136.—Projection of the probable number of cars and trucks in use in the United States by years, 1920–1940; prepared by Commercial Research Department, Franklin Automobile Co., and published in Automotive Industries, April 28, 1921.

greater than its present dimensions and find new oil sources of sufficient magnitude and accessibility to support this expansion. The alternative, aside from a curtailment of the demand, is a change in fuel and engine in the direction of extracting a much greater motor-fuel service from a much smaller volume of raw material.

Adaptability of the Internal Combustion Engine.—The automotive engine has developed and become standardized in its main features on the basis of cheap and volatile gasoline. Its improvement has for the most part followed the direction of convenience and performance, with secondary consideration to fuel economy. This trend has been sustained to the present time by the existence of a highly stimulated oil production, providing, until lately, gasoline capacity in excess of gasoline demand. So long as this condition obtained, there was no need apparent for the automotive industry to concern itself with considerations of fuel supply, but now, with the gasoline capacity of the country beginning to give indications of strain, while the motor-fuel demand is just fairly getting launched, the question arises whether the exigencies of the future will allow the engine type continued freedom of development in luxury directions, or will force adaptations to meet the exactions of the fuel situation.

Automotive apparatus is mechanically responsive to changing requirements, but its adaptation to new conditions is retarded by the time required to perfect mechanical developments and the counter advantages to be gained from quantity production and standardization, with their resistance to change. So far-reaching and insistent, indeed, are the claims in favor of holding fast to established standards, that departures can be made only at great cost and in response to powerful reasons. Anticipatory action becomes peculiarly difficult in the face of these circumstances. Recognizing the strength of the factor opposing changes in engine type and seeking to force the fuel supply into channels fitting the established standards, we may examine the fuel supply with a view to determining if present engine practice can be advantageously maintained, and, if not, along what lines changes are likely to be made.

The Supply of Motor-fuel.—The motor-fuel in dominant use in the United States is gasoline, a mixture of volatile hydrocarbons won from crude petroleum by processes of distillation. Kerosene, fuel oil, lubricating oils, and various by-products are produced at the same time, and bear an intimate relation to gasoline, in respect both to price and the relative quantities produced. The output of these products in 1920 is shown in Table 117.

The country's supply of gasoline depends upon the output of domestic petroleum and the gasoline-producing capacity of this

material, the quantity of foreign petroleum made available through importation, and the extent to which supplemental means for expanding the supply are developed.

TABLE 117.—PRODUCTION OF PETROLEUM PRODUCTS IN THE UNITED STATES IN 1920

(Data from U. S. Bureau of Mines)

Product	Millions of Barrels	Per Cent
Gasoline	116.2	24.5
Kerosene	55.2	11.7
Gas and fuel oil	211.3	44.6
Lubricating oils	24.9	5.3
All others	47.7	10.0
Losses	18.7	3.9
Total	474.0	100.0

The Supply of Domestic Petroleum.—The supply of crude petroleum available in this country depends upon the unmined reserve and the rate at which it may be won. The petroleum resource in the United States has been inventoried by the U. S. Geological Survey in 1908, 1916, and 1918;[1] each time in greater detail. The results obtained are highly significant, especially as regards the meagerness of the reserve, which approximates 6 billion barrels when adjusted for Jan. 1, 1921 (see Fig. 137), and in respect to the fact that between 1908 and 1918, in spite of an exceedingly aggressive campaign of exploration, the oil taken from the ground exceeded the additions made to the reserve through new discoveries. Those who count upon new discoveries to make up for the progressive depletion of the reserve overlook the fact that for over ten years new discoveries have been failing to do so.

At the same time the production of crude petroleum has been steadily mounting to its present enormous figure, 443 million barrels for the year 1920 as contrasted with 210 million barrels in 1910. The growth in output has been sustained, not primarily by the discovery of new oil-fields, but largely by the cumulative tapping of an increasing number of rich spots in inventoried territory. There is obviously a limit to an output supported by such a train of circumstances; there are strong engineering and economic reasons for believing that the production of crude petroleum in the United States has virtually

[1] See pages 18–21.

reached its maximum annual rate in 1921, and that the country will thereafter pass into a period of a declining and more costly production. (See Fig. 4, page 20.)

The Gasoline Factor.—The output of gasoline approximates[1] the production of crude petroleum multiplied by its commercial-gasoline factor, which in 1920 was 21.8 per cent.[2] This factor, like the supply of crude petroleum, is itself a variable figure depending upon the proportion of the crude supply subjected to refining, the natural gasoline content of this quantity, and the extent to which

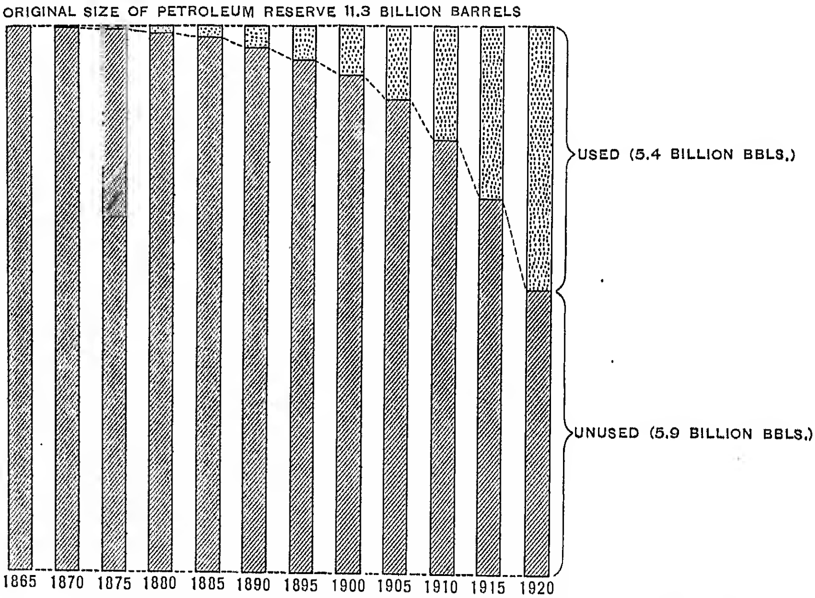


FIG. 137.—The waning reserve of petroleum in the United States.

means are used for forcing the gasoline yield above the natural gasoline content. Obviously, as long as the natural gasoline is not fully extracted from the available crude, there is scant economic room for the development of roundabout, i.e., more intricate, more costly means for producing gasoline. This was the situation that

[1] Because of the subordinate item of the gasoline produced from natural gas, the relation is not an exact equality.

[2] The commercial-gasoline factor is here used to designate the percentage of gasoline obtained from the crude consumed; the commercial-gasoline factor should be distinguished from the natural-gasoline factor, which represents the percentage of natural gasoline present in the crude. The former percentage has increased until it has exceeded the latter. The natural-gasoline content of the domestic production of crude petroleum in 1920 was approximately 21.6 per cent; of the imported crude, approximately 8 per cent.

prevailed in the United States until recently; this is why natural-gas gasoline, cracked gasoline, and low-volatile gasoline are all recent commercial developments.

The proportion of the crude supply subjected to refining has been steadily increasing until, in 1920, of a total consumption of 531 million barrels of crude petroleum in the United States, 434 barrels or 82 per cent was run to stills. While the statistics may not indicate the precise situation in this respect, the quantity not refined represented in the main heavy, non-gasoline crudes used directly for fuel purposes. Thus practically the whole supply of crude has now come to be requisitioned for gasoline production. This is to say that the readiest means for increasing the supply of gasoline, i.e., refining a progressively larger percentage of the crude produced, has been virtually forced to its limit; the "gasoline slack" within the crude production has been taken up. Thus the most potent circumstance that has thus far enabled the demand for gasoline to increase without a concomitant increase in price is no longer in existence. Further expansion in gasoline output will lie through more difficult avenues than that of merely increasing refinery capacity.

While dependent primarily upon the quantity of crude refined, the output of gasoline is at the same time a function of the average composition of the various crudes that go to make up the total supply. Since crude petroleum varies in its natural-gasoline content from about $1\frac{1}{2}$ per cent in the case of heavy, asphaltic oils to 30 per cent or more for light, paraffin oils, it is evident that the gasoline supply will be strongly influenced by the dominant type of oil. As the high-gasoline crudes were the first to be exploited in this country, the unmined supply of petroleum has been selectively reduced in gasoline capacity, so that the crude production of the future will show a lower natural-gasoline factor than the crude supply of the past. While this matter cannot be expressed quantitatively, in very rough terms it may be noted that the high-gasoline crudes are about half exhausted, while the low-gasoline crudes, originally of about equal magnitude, are only about a third used up. In other words, the country's gasoline capacity is being drawn upon more rapidly, and hence exhausted more quickly, than is indicated by the condition of the crude supply viewed alone. This tendency was of no immediate consequence so long as it could be compensated by merely refining a greater proportion of the output of crude; but now, since practically all of the domestic crude is used for gasoline extraction, a decline in gasoline content can be offset only by shoving crude production to a higher figure than would otherwise be necessary, or else through a still greater use of means for wresting an unnatural percentage of gasoline from the crude obtainable.

The estimated supply of natural-gasoline present in the unmined reserve of crude petroleum is shown in Table 118.

TABLE 118.—THE ESTIMATED NATURAL-GASOLINE CONTENT OF THE UNMINED SUPPLY OF CRUDE PETROLEUM IN THE UNITED STATES ON JANUARY 1, 1921

(In millions of barrels)

Fields	Unmined Supply of Crude Petroleum	Estimated Natural-Gasoline Content
Appalachian	491	147
Lima-Indiana	33	7
Illinois	152	30
Kansas-Oklahoma	1465	366
North Texas	262	87
North Louisiana	53	15
Gulf Coast	703	11
Wyoming	370	110
California	2043	204
Others	350	88
Total	5922	1065

In respect to imported crudes, the natural gasoline content has varied from virtually zero up to a maximum of 12 per cent; and the bulk of the oil in sight in Mexico, Central America, and South America corresponds more closely to the types already imported than to the high-gasoline crudes of the Appalachian and Mid-Continent fields which have been the bulwark of gasoline production in this country.

Enlarging the Gasoline Factor.—The means for producing more gasoline than may be obtained by subjecting the total supply of crude to straight refining are: (1) increasing refinery efficiency, (2) blending high-volatile natural-gas gasoline with low-volatile refinery gasoline, naphtha, and kerosene, (3) extending the use of cracking in refinery practice, and (4) lowering the volatility of gasoline. All four means are increasing in use. For the sake of brevity the first two may be passed over with the comment that, while important, they have quantitative limitations which prevent them from broadly affecting the situation. This is not true of the second two, the limitations of which are of a different order.

Cracking is a process attachable to straight refining, by means of which low-priced distillates such as gas-oil are rerun under more rigorous conditions and partly converted into gasoline. So far cracking has operated commercially only upon distillate fuel oil

and has yielded gasoline to the extent of 30–40 per cent of the oil treated. These conditions would appear to limit the volume of gasoline ultimately attainable by cracking to around 25 per cent of the total supply of fuel oil. There is also the element of time to be reckoned with before cracking could expand to its limit, while counter demands affecting distillate fuel oil are arising which may restrict the quantity available for cracking. The process, moreover, can be profitably operated only so long as a favorable differential exists between the market price of distillate fuel oil and the selling price of gasoline, hence the growth of cracking to a point restricting counter demands may be expected to institute an economic cycle where further cracking may be realized only upon the basis of higher levels of price for gasoline. On the whole, therefore, it would appear that cracking, while of the utmost importance for the present, will prove incapable of augmenting the gasoline supply in adequate volume with sufficient economy and celerity to sustain the future demands of automotive transportation.

The fourth means for enlarging the output of gasoline independently of the production of crude is through lowering the volatility of the product. The less specialized the engine fuel in respect to volatility, the more can be produced from a given quantity of crude by the processes of refining in general use. By a change in character, the supply of "gasoline" can be enlarged, slowly or rapidly at will, without material refinery changes, until it is two to three times the present figure, even with no increase in the supply of crude. Since the materials requisitioned in such a change are the basis of kerosene and fuel oil, which can be replaced almost entirely by coal and its products, the transition may be made without a basic disturbance of the country's economic fabric and without setting up counter forces tending to turn back the tide. The practical limit to this enlargement, however, is set by what the standardized automotive engine will accept in the way of fuel. The progress of gasoline in this direction has already gone as far as practicable under existing standards. A critical point has been reached in the end-point of gasoline, where a further upward change will increase consumption more than it would increase production and thus deplete rather than augment the total available fuel supply.[1] If further gain is to be made here, therefore, either the character of the fuel or the engine, or both, must change. If the fuel current finds an unbreakable dam at this point, the whole pressure of advance will be thrown back into the channels already reviewed. But since the past few years have seen the end-point of

[1] H. C. Dickinson and S. W. Sparrow, Possible Fuel Saving in Automotive Engines, American Petroleum Institute, November 17, 1920

gasoline steadily rising, in spite of all opposition, while the engine equipment has already been forced to make superficial concessions to this tendency, it is apparent that the channels of crude production, cracking, etc., have already demonstrated their incapacity unaided to accommodate the rising flood of gasoline demand. If these mainstays of automotive transportation are failing to meet the issue now, it is hazardous to count upon complete relief in that quarter when the pressure focusing there is rapidly increasing.

Bearing of Foreign Deposits upon the Situation.—The limitation to the gasoline supply arising from the domestic production of crude petroleum has been generally recognized, but deposits in Mexico and other foreign regions are counted upon in many quarters to fill in the gap. It has been shown elsewhere (see Chapter XXV), however, that the proven oil-pools of Mexico, the principal standby, are well-nigh exhausted, and an interval of years must elapse before the output of that country can be strongly reinforced by newly developed territory. Also the exploitation of other foreign deposits involves an element of considerable time, not to mention restrictions of a political and financial character. (See Chapter XXIV.) Moreover, much of the prospective territory most convenient of access to the United States gives promise of yielding in the main low-gasoline crudes such as those that characterize the Gulf Coastal Plain of the United States and Mexico.

On the whole, foreign deposits do not appear to be capable of compensating for the decline due in domestic output and of supporting the increments to demand as well, on the basis of the present disposition of products. Indeed, the richest known deposits of Mexico were exploited and exhausted before the output could be brought significantly into motor-fuel production; and the same outcome will probably characterize to some degree the development of rich deposits further afield. In short, the demands concentrating upon crude petroleum the world over are such that the volume available for consumption in the United States can scarcely be expected to continue to increase at the rate characterizing the past decade.

Significance of Supplementary Motor-fuels.—The petroleum industry is so firmly established and produces such a range of products other than gasoline, that no motor-fuel of non-petroleum origin need be counted on as capable of displacing gasoline. Substitute fuels are to be regarded as supplementary resources, capable of affecting the situation broadly only as petroleum relinquishes the field through exhaustion.

There are three supplementary motor-fuels in sight—benzol,

alcohol, and shale-oil distillate.[1] Benzol and alcohol, in the form of appropriate blends, are already coming on the market in small quantities; shale-oil distillate may be expected to contribute only on a higher level of price than at present obtains. As to resource capacity, benzol is a by-product of coal, and the quantity produced is dependent upon the coal subjected to by-product distillation; benzol will be manufactured in constantly increasing volume, but the total supply, under present technology, can never fill more than a small part of the motor-fuel requirements. Alcohol may likewise slowly increase in volume but after the utilization of a few readily obtainable waste products, its manufacture will come into competition with food demands and hence meet a critical limitation in its further expansion. Shale-oil distillate is derivable from a resource practically unlimited in size, but a large output must wait upon the upgrowth of a new industry in which but the merest start has been made.

On the whole, supplementary motor-fuels, while of the utmost eventual importance and deserving of the most vigorous development, can scarcely be counted on to make notable independent contributions to the motor-fuel supply in the immediate future. Their chief significance for the present would appear to lie, not in their volumetric importance, but in their apparent ability to raise some of the intermediate petroleum distillates to motor-fuel rank and improve the operating efficiency of heavy gasolines when appropriately blended with these substances.

Fuel and Engine Already Changing.—It is apparent from the foregoing review that the demand for motor-fuel has already begun to outdistance the supply of gasoline, with the result that the character of the fuel is changing and the appliance is beginning to adapt itself to this change. It is furthermore apparent that the demand in the years ahead will assume such tremendous proportions in the face of a resource whose ultimate size is limited and whose rate of production is restricted, that motor-fuel service can be sustained by sheer volumetric increases in supply in still less degree and additional changes may be expected in both the fuel and the appliance making for higher net efficiency. It is a fair assumption that the insistence of the demand will exhaust all possibilities in both engine and fuel before a curtailment in automotive transportation would be accepted.

Changes in the Appliance.—The automotive appliance, while a triumph of engineering as regards simplicity and reliability, leaves much to be desired in the way of fuel economy. Changes in the appliance hold the possibility not only of increasing the mileage

[1] See Chapter XXI for a fuller discussion of supplementary motor fuels.

obtained but also of permitting the physical supply of fuel to be enlarged through the inclusion of non-volatile distillates not useful as motor-fuel in present engines. The possibilities of appliance change fall chiefly into four categories, some of which involve coordinate changes in the fuel itself: (1) the distribution of the fuel to the cylinders may be improved; (2) the combustion of the fuel in the cylinders may be made to yield higher efficiency; (3) the design of the appliance may be changed in the direction of smaller, lower-powered units, better adjustment of the load factor through an additional gear-shift, and the like; and (4) the engine type may be changed in favor of the injection engine, the steam engine, or even some other type yet to be perfected, such as the gas turbine.

(1) The less volatile the fuel, the greater the difficulty in gaining proper vaporization, even distribution to the cylinders, and no condensation in the cylinders with consequent dilution of the crank-case oil. With the rise in end-point already experienced with gasoline, the old methods of distributing the fuel as a cold mixture have proved inadequate, and various means have been commercially developed to apply heat to the charge in order to improve its distribution. There is considerable difference of opinion as to what constitutes the best means of preparing the fuel for the engine. The hot-spot manifold concentrating the heat where the liquid strikes the walls, the manifold completely jacketed by the exhaust so that the entire mixture is heated, the hot-air stove which heats only the air going to the carburetor, methods for preparing "superheated" gas, and many other variants are all coming into prominence. All resources have not yet been exhausted in this respect, and further improvements in the induction system and the extension of these improvements to all units may be looked for.

Effective distribution, however, while leading to a more efficient utilization of the fuel, is only one, and perhaps a minor, part of the problem of improvement facing the automotive appliance.

(2) A second possibility of improvement in the appliance is the matter of gaining greater efficiency in combustion. The thermal efficiency of the carburetion engine is primarily dependent upon the compression ratio. As the gravity of the fuel is lowered (or the end-point raised), the compression of the engine must be lowered to prevent the phenomenon of detonation called knocking. And as the motor builder lowers the compression of his engines, they operate less efficiently and require a greater quantity of fuel per mile. The problem of raising the efficiency of combustion, therefore, is not entirely a mechanical one; this matter involves the chemical character of the fuel quite as much as it does the mechanical nature of the

appliance. It can be solved only by coordinate attention to fuel and engine. The work of Kettering and Midgley has pointed the way to changes that may become effective in the direction of adding certain components to the fuel that will permit its efficient employment in engines of higher compression than prevalent to-day. The same means will also allow a larger proportion of the crude to be effectively employed in engines of present-day compressions pending the more fundamental change.

(3) Aside from the improvements in the distribution and combustion of the fuel, mechanical changes are possible in other respects that would greatly increase the mileage per gallon of fuel. In the first place, the employment of exceedingly high-powered cars could be curtailed; but this is a minor matter compared with the fact that all cars are adjusted to carry a peak load of performance far in excess of normal running requirements. And this extra ability, called into use only now and then, is paid for by an increased consumption of gasoline whenever the car is running. In other words, the average car runs at its maximum efficiency only at full load with open throttle; under these conditions the car may attain a thermal efficiency of 20–25 per cent. But under ordinary road conditions the car is running most of the time at part load, and the efficiency drops very rapidly as the load is reduced. The operating efficiency of the typical car, therefore, is only around 5–10 per cent, from a quarter to a third of its maximum. By making smaller, lower-powered motors, some of the luxury qualities of the present automobile would be sacrificed, but a considerable gain in fuel economy would be attained.

Even with cars as they are to-day, a fuel loss running upwards of 25 per cent results from improper carburetor adjustment leading to the employment of an over-rich mixture. Experiments on exhaust gases conducted by the U. S. Bureau of Mines,[1] in connection with the ventilation of the Hudson River Vehicular Tunnel, have demonstrated that the combustible gas in the average automobile exhaust contains nearly 30 per cent of the total heat in the original gasoline. Careful carburetor adjustment should result in saving half of this quantity. The great majority of passenger cars and trucks are operated on rich mixtures suitable for maximum power but very wasteful from the standpoint of gasoline economy; the average carburetor is set for winter operation and is not changed in the summer. The public does not appreciate the saving in gasoline that would result from the use of lean mixtures.

[1] Fieldner, Straub, and Jones, Automobile Exhaust Gases and Vehicular-tunnel Ventilation, Jour. Soc. Aut. Eng., April, 1921, pp. 295–305.

(4) In addition to the improvement in respect to fuel economy attainable with the present type of motor, the possibility of a radical revision in engine type should be borne in mind. The injection type of high-compression engine, which could burn all types of liquid fuels, is thought by some engineers to have been underestimated in this country. The steam engine also has its advocates, and there are other possibilities such as the gas turbine, which may not have been sounded. The future in these respects can scarcely be foreseen, although the development of automotive transportation to its present status on the basis of a carburetion engine places the powerful force of standardization behind the existing type.

Changes in the Fuel.—It has been seen that the supply of motor-fuel has been maintained thus far mainly by a volumetric increase in the output of crude petroleum, supplemented by a physical conversion of the heavy molecules of distillate fuel oil by cracking into gasoline. Should the demand exceed the combined ability of these first two expedients, as seems inevitable, mechanical changes in the appliance and chemical changes in the fuel, both already beginning to come into evidence, will be called into action in still further degree. It thus appears that there are four major factors involved; volumetric increase in the supply; physical changes in the fuel; mechanical changes in the appliance; and chemical changes in the fuel.

The possibilities of adding to petroleum distillates certain compounds, such as benzol, aniline, or alcohol, which will increase the operating efficiency of the fuel in existing appliances and even permit the appliance to change in directions making for greater efficiency, have already been touched upon. (See Chapter XXI.) Such possibilities also raise the question of whether changes may not be attainable in petroleum refining which will enable certain properties to be directly fabricated into the fuel such as will adapt it to more efficient utilization. This field has been largely overlooked in the past and holds considerable promise.

Coordination of Engine and Fuel.—The outstanding feature of the motor-fuel problem is the interdependence of the fuel and appliance, and the degree to which any change in one has an immediate bearing upon the other. The most difficult problem ahead is not the matter of engineering and research, but the economic issue of adjusting the efforts in respect to both fuel and appliance to the end that the maximum service may be gained from automotive transportation. The supply and price of fuel represent the limiting factors in automotive transportation and the best efforts of all concerned are needed to hold off restrictions on this score.

Volumetric increases in supply have apparently been shoved almost to their maximum; the physical process of cracking holds further possibilities of expansion, although already called into extensive use; mechanical changes in the appliance give promise of considerable extension; and chemical changes in the fuel offer further possibilities. Upon the interplay of these factors, the future of automotive transportation rests. Much will depend upon the degree to which this interplay is brought under control in a united, constructive effort to solve the problem.

CHAPTER XXIII

THE CITY-GAS PROBLEM

THE manufacture of city-gas, widely used in American municipalities, is at present dependent upon one of the petroleum products, gas oil, for its principal raw material. The growing fuel requirements of automotive transportation have recently set up a counter demand for gas oil for use in the manufacture of a supplementary supply of gasoline, and this competitive demand in 1920 critically restricted the supply of gas oil available for the manufacture of gas as well as sharply advanced its price to a level which the gas companies could meet only under a substantial increase in the rates charged for city-gas.

Upon the further development of the petroleum situation, the supply of gas oil may be expected to become still more restricted in volume and progressively higher in price, until finally it will be generally apparent that the manufacture of city-gas can no longer economically rely upon this source of supply, and attention will then turn toward making gas without the use of gas oil. Gas of this character can be readily and cheaply manufactured, but its widespread development will entail changes in the present installations and revision in the standards of concentration now imposed by the municipalities upon the public utilities serving gas. Such changes, however, are inevitable and are already overdue.

Types of City-gas.—There are four principal types of manufactured gas employed in American cities: carburetted water-gas, coal-gas, oil-gas, and coke-oven gas.[1] The relative importance of these four types is shown in Fig. 138, where the dominance of carburetted water-gas is apparent.

Carburetted water-gas is made by passing steam through incandescent coke or anthracite coal, and enriching the resultant water-gas with gas oil. Average practice requires about 3.5 gallons of gas oil and 35 pounds of coke or anthracite to yield a thousand cubic feet of city-gas of present-day quality.

[1] A good general description of the main types of city-gas appears in Standards for Gas Service, U. S. Bureau of Standards, Cir. No. 22, 1920.

Coal-gas is made by distilling a volatile, bituminous coal in closed retorts, leaving a residue of coke to be disposed of. In many instances, the coke is employed in turn as a raw material for the manufacture of carburetted water-gas which is then mixed with the coal-gas.

By-product coke-oven gas is an incidental product to the manufacture of metallurgical coke, and is available for use in some cities located in the neighborhood of industrial coke-making establishments.

Oil-gas is made entirely from oil, and is manufactured only in the Far West where gas-making coals are not readily available.

Development of City-gas.[1]—The earliest practical application of gas was made toward the close of the eighteenth century in England. In 1812 the City of London Gas Light Company was formed, and in 1816 gas-lighting was introduced into Baltimore in this country.

Gas accordingly developed as an illuminant, and quite naturally its value was determined by its illuminating capacity. In the early stages of the industry, therefore, gas came to be measured in terms of its candle-power, the intensity of light produced when burned in an open-flame burner under specified conditions. Practically all of the gas manufactured in the early days of the industry was coal-gas.

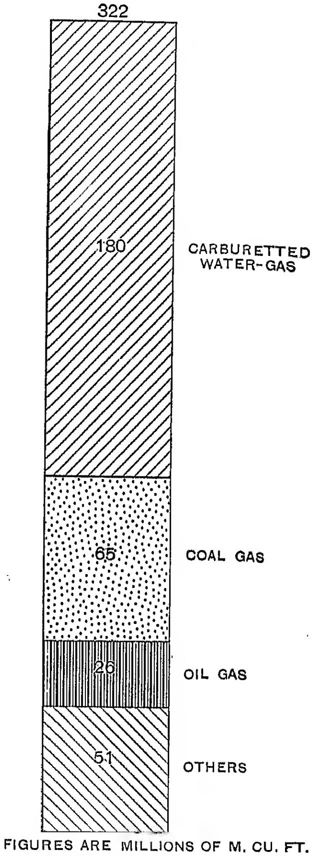


Fig. 138.—Estimated production of artificial city gas in the United States in 1919; data from American Gas Association.

Around 1880 a method was developed for rendering water-gas, which could be much more cheaply manufactured than coal-gas but lacked luminosity, available for illumination by enriching it with gas oil. Since that time, carburetted water-gas has enjoyed a rapid growth in the United States, far outdistancing the city-gas manufactured by other methods. The expansion of the carburetted water-

[1] For a constructive discussion of the gas situation, see R. B. Harper, City-gas of the Future, Jour. Western Society Engineers, January, 1921, pp. 1–15.

gas process was made possible by the era through which the petroleum supply was passing, with production crowding demand and yielding a cheap and abundant supply of gas oil to the gas manufacturer.

In the meantime a gradual but almost complete revolution in the utilization of gas has been taking place, accompanied of late years by profound economic changes in the petroleum supply, but the processes of manufacturing gas remain to-day practically unchanged. For the first sixty or seventy years following its introduction in this country, city-gas was almost solely used for lighting houses and streets by means of open flames depending for their luminosity upon certain hydrocarbons derived from volatile bituminous coals or gas oils, which emitted considerable light when the gas was burned without sufficient air to maintain complete combustion.. In contrast to this practice, city-gas is now used almost exclusively for its heating effect gained from the so-called Bunsen, or non-luminous flame. This type of flame is designedly non-luminous, sufficient air being mixed with the gas before it reaches the zone of ignition to lead to complete combustion, leaving no unburned particles to become incandescent. This mode of combustion gives higher efficiency and flame intensity than the open-flame method which enjoyed its luminosity at the expense of these qualities. The luminous flame is now practically obsolete, and the Bunsen flame is employed in almost all gas-burning apparatus, such as ranges, stoves, water-heaters, and mantle lights. The development of the incandescent mantle emancipated even gas-lighting from its dependence upon potentially luminous constituents in the gas.

In spite of this revolution in the utilization of gas, many municipalities still require the gas companies to continue to introduce into the gas these hydrocarbons, as if the product were going to be used in the old-fashioned open-flame burners; and in 1920 these same municipalities even granted substantial increases in rates in order that the gas companies might afford to buy the costly hydrocarbons requisite to cater to a need long since non-existent. Such was the situation in New York City, the largest gas-consuming center in the country.

The change in the method of utilizing city-gas has resulted in a tendency on the part of the regulating authorities to impose upon the gas manufacturers heating-value standards in addition to the existing candle-power requirements. In many localities, however, the public utility commissions have discarded the candle-power requirements, though still maintaining heating-value standards substantially the same as those characteristic of gas meeting the discarded candle-

power requirements. Thus, it has happened that heating-value standards have been determined for the most part on the basis of what happened to have been the heating value of the gas designed to be used in luminous flames, and " not on the basis of processes which were designed to economically utilize the gas-making materials, as provided by Nature, in such a manner as to produce the greatest total heating value per unit." In short, the presence of costly hydrocarbons in the gas is still required to meet the heating standards imposed as an inheritance from the days of candle-power requirements.

Accordingly, the manufacture of city-gas to-day is handicapped in many instances by obsolete lighting standards, and in all instances by heating standards involving but little diminution from the old candle-power requirements. Wherever the obsolete form has been discarded, the old substance has been preserved.

The Rôle of Gas Oil.—The function of gas oil is to add to the gas those hydrocarbons needed to enable the gas to meet the candle-power or heating-value standards imposed by law. Water-gas before the addition of gas oil, has a heating-value of only 300 B.t.u.[1] per cubic foot, whereas the standards usually prevailing for city-gas run from 520–600 B.t.u. The additional B.t.u. are contributed by the gas oil. The resulting gas is more concentrated than the straight water-gas and meets the legal requirements, but has no advantage in utilization where the Bunsen flame is employed, since gas of whatever concentration must be diluted with air to a combustible mixture carrying only about 100 B.t.u. to the cubic foot before it can be efficiently burned.

The Growing Stringency of Gas Oil.—Of recent years, especially since 1915, the supply of gas oil has come more and more under requisition as a raw material for cracking into gasoline. In 1920 approximately 12 to 15 million barrels of gasoline were made from gas oil, requiring some 30 to 40 million barrels of the latter. The growth of this new demand for gas oil has been rapid, and has introduced a new and perplexing factor into the city-gas problem. The effect has already registered in three directions.

In the first place, the quality of the gas oil has deteriorated, the gas oils highest in carburetting quality having been partly diverted into cracking stills and their place taken by heavier oils less susceptible to yielding gaseous hydrocarbons. Cracking into gasoline in the oil refinery and cracking into oil-gas in the gas plant, indeed, are very similar processes. The trend in the average quality of gas oil is shown in Fig. 139.

[1] B.t.u. is the abbreviation for British thermal unit, the quantity of heat required to raise 1 pound of water 1 degree Fahrenheit.

In the second place, there has been a tendency to reduce the quantity of gas oil used, as a result of cutting as closely as possible to the minimum limits of the B.t.u. standard as well as slightly lowering this standard in some localities. The tendency toward the use of a tapering quantity of gas oil per M cubic feet of gas is shown in Fig. 140.

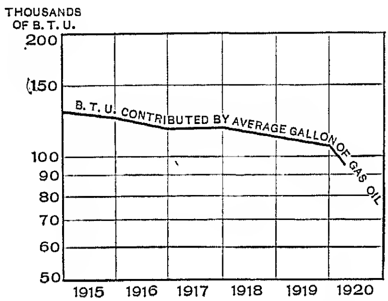


Fig. 139.—Deterioration in the quality of gas oil, 1914–1920; data from R. B. Harper.

In the third place, a notable advance in the price of gas oil has taken place, which has considerably increased the cost of manufacturing gas. In 1914, 1 cent's worth of gas oil contributed to the finished gas over twice the number of B.t.u. derived from 1 cent's worth of generator fuel (coke or anthracite). Since that time, the relative contribution made by gas oil has been decreasing more rapidly than the contribution made by generator fuel, until in 1920 the cost of heat units of gas-oil origin was higher than that of an equivalent number produced from generator fuel. The tendency for gas oil to impose a growing burden of expense upon the manufacturing process is shown in Fig. 141, which also suggests that the divergence is going to increase still further.

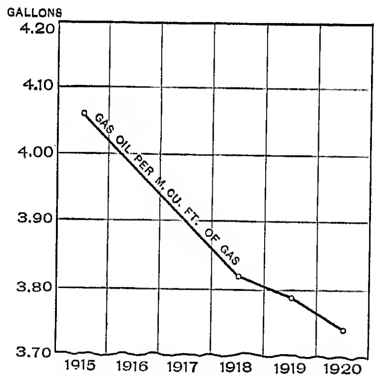


Fig. 140.—Trend in the use of gas oil per thousand cu. ft. of carburetted water-gas manufactured in the United States by years, 1915–1920; data from R. B. Harper.

The Impending Shortage of Crude Petroleum.—A tightening up in the supply of gas oil has already taken place under the influence of the gasoline requirements of automotive transportation, in spite of a rapidly mounting output of crude petroleum. In view of the relative smallness of the petroleum reserve, both in this country and Mexico, and the close approach to the maximum rate at which this reserve may be drawn upon, the supply of crude petroleum will inevitably display a retardation in its growth which will restrict the volume of products available for consumption. (See Fig. 142.)

This outcome may be expected to impair still further the availability of gas oil and contribute an additional and continuing impetus to its upward move in price.

Use of Gas Oil Already Uneconomic.—The relative increase in the price paid by a typical gas company for gas oil and generator fuel

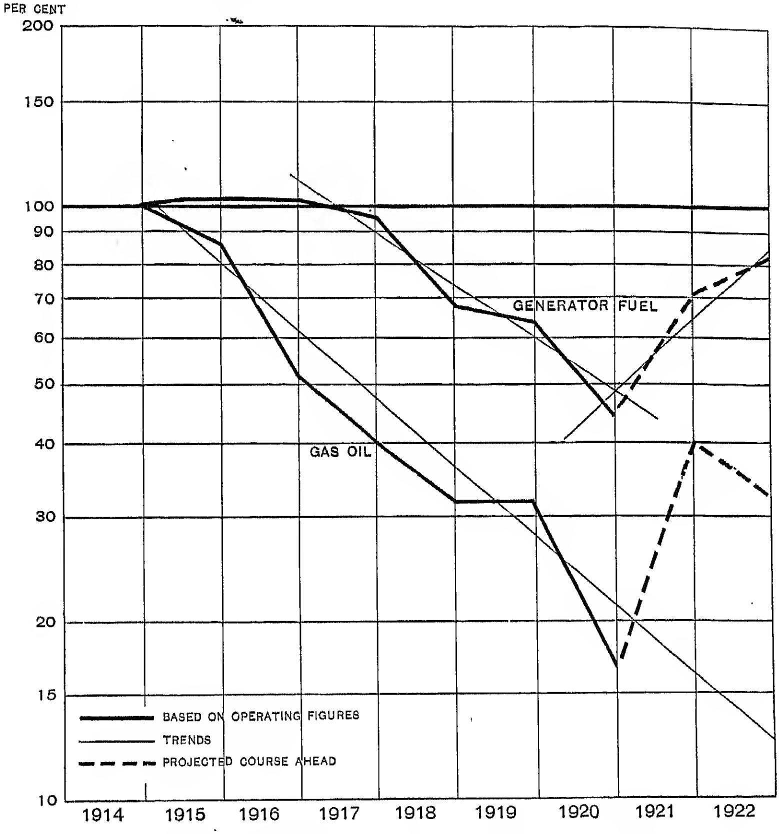


Fig. 141.—Trend of the contributions to the heating value of carburetted water-gas made by one cent's worth of gas oil and generator fuel, in percentages of the contributions made in 1914; data for 1914–1920 from R. B. Harper; projection, 1921–1922, by author.

for the period, 1914–1920, is shown in Fig. 143. The average cost of gas oil to a large number of gas companies is given in Table 119.

It is apparent from the data given that the sharp upward trend in the price of gas oil, which arises in the main from fundamental changes in the petroleum situation, is rendering the use of gas oil increasingly costly. Fig. 144 shows plainly the weight of this factor in the cost of gas. A cubic foot of typical carburetted water-gas

containing 570 B.t.u. may be looked upon as composed of 300 B.t.u. contributed by generator fuel and 270 B.t.u. derived from gas oil. Several years ago the 270 B.t.u. cost about the same as the 300 B.t.u. In 1920 the 270 B.t.u. were much the more costly, and the tendency is toward a growing discrepancy between the two. In other words, so far as the cost of materials is concerned, the use of gas oil in manufacturing city gas has become fundamentally uneconomic,

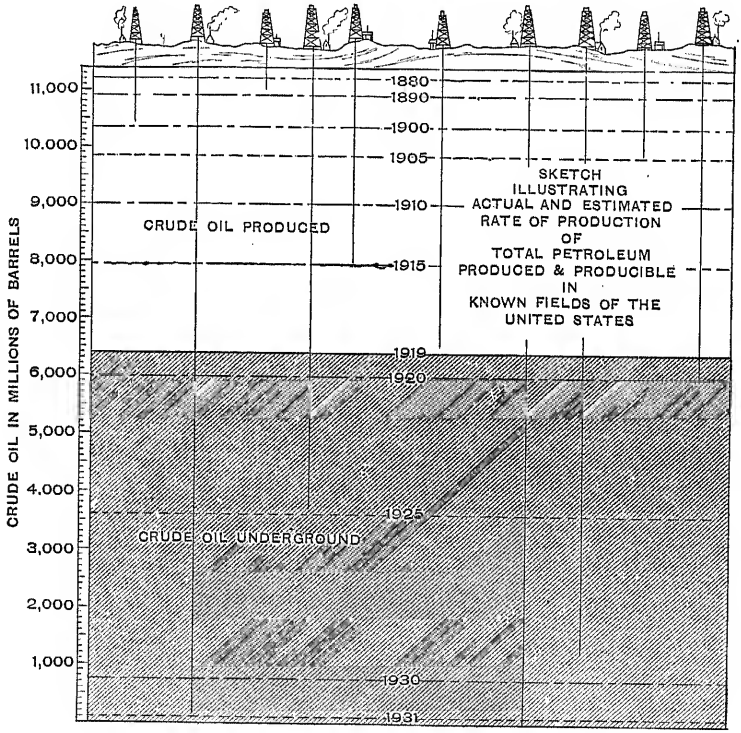


Fig. 142.—The unmined reserve of crude petroleum in the United States; after R. B. Harper, based on data from U. S. Geological Survey

in spite of a temporary reversal in 1921. Accordingly, the manufacture of carburetted water-gas has passed through its period of usefulness and is now obsolescent because of the diversion of its principal raw material into a channel of higher economic rank.

Increase in Gas Rates no Solution.—The growing cost of gas oil has borne heavily upon the cost of manufacturing gas, as indicated in Fig. 144, and the gas companies met the situation by entering pleas for higher rates, which in most instances were granted. While increases in gas rates will support a rising price of gas oil

and for a time enable the gas companies to continue to compete with automotive transportation for this raw material, such increases will not alter the fundamental situation; they represent, on the

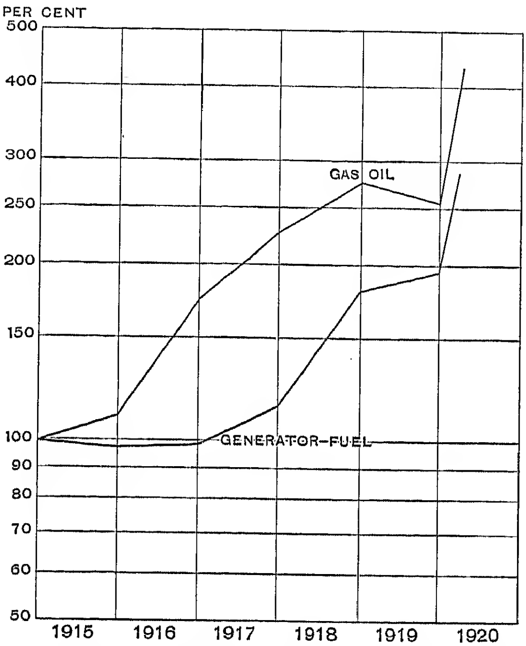


Fig. 143.—Rise in the average price of gas oil and generator fuel, 1914–1920, in percentages of the average prices in 1914; data from R. B. Harper.

Table 119.—Average Cost of Gas Oil to a Large Number of Gas Companies by Years, 1910–1920

(Data from American Gas Association)

Year	Cents per Gallon	In Per Cent of Price in 1913	Year	Cents per Gallon	In Per Cent of Price in 1913
1910	3.08	71	1916	4.14	95
1911	2.96	68	1917	5.76	132
1912	3.40	78	1918	7.90	182
1913	4.35	100	1919	7.05	162
1914	4.35	100	1920	12.62	290
1915	3.57	82			

contrary, a temporizing measure but no final solution to the problem. In fact, a succession of such increases in gas rates will insti-

tute a cycle which will react upon the price of gasoline as well as upon the price of city-gas, playing the two against each other with neutral effect and leaving the basic issue still unsolved.

Fundamental Changes in Gas Manufacture Necessary.—Sufficient evidence is now available to indicate that the manufacture

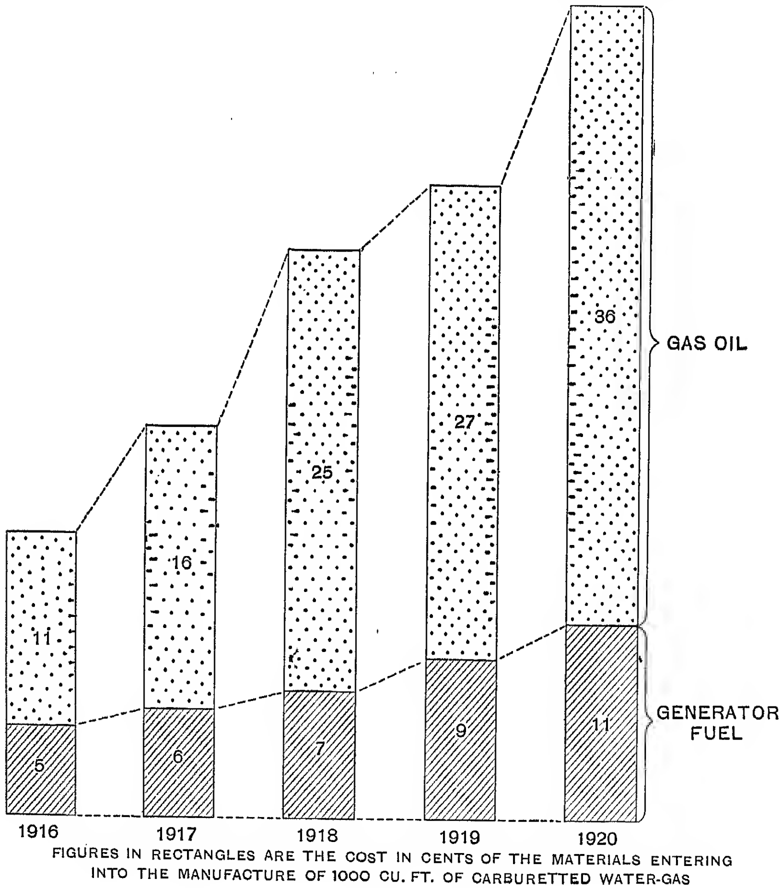


Fig. 144.—Relative cost of the quantity of gas oil and generator fuel entering into the typical manufacture of 1000 cu. ft. of carburetted water-gas, by years, 1916–1920.

of carburetted water-gas must give way to other processes more suitable to the changed conditions of fuel supply. The outstanding fuel dependency of this country is bituminous coal, and the city-gas of the future must be derived from this source. The conditions requiring the use of a concentrated, luminous gas are no longer

existent; and the means for preparing such a gas cheaply are no longer attainable. The situation has finally advanced to the point where there is no choice in the matter. The methods of manufacturing city-gas are bound to undergo fundamental changes in the next decade, and economic pressure may dictate more rapid alterations than appear practicable at the present moment. The changes that appear inevitable lie in the direction of complete gasification of bituminous coal, with the preparation and distribution of a less concentrated gas than that now in general use in cities.

B.t.u. Standards Will be Lowered.—At the present time the situation is crystallized and progress blocked by virtue of the legal B.t.u. standards in vogue which do not admit of processes yielding low-cost gas because such gas is invariably leaner than the standards require. There has already come into evidence a distinct downward trend in heating-value requirements; some municipalities now have a 520 B.t.u. minimum, whereas in Canada a 450 B.t.u. standard has been established. It is inevitable that the present high standard will be removed by degrees and the field thus opened to the employment of modern and efficient means for manufacturing gas.

A Transition Period Ahead.—In addition to the obstacle of high heating-value requirements, which is an inheritance from the days when gas was burned in open-flames for purposes of illumination, progress toward gaining low-cost gas will be retarded by the past failure to prepare for the obsolescence of present installations and equipment—a failure which leaves a vast investment amortized to an insufficient degree as well as a wide range of equipment which can be adapted to the new conditions with difficulty. The situation is indeed perplexing and raises problems of the first magnitude—problems, too, made none the easier because they lie in the field where public oversight is exercised in a manner unfortunately lacking in technical proficiency.

The transition to low-cost gas, however, can be made, and the gas industry emancipated from its present dependence upon gas oil, if constructive and concerted attention be accorded the matter. A graded reduction in B.t.u. standard, accompanied by a decrease in the quantity of oil employed as well as by a change to heavier oils not so desirable for cracking into gasoline, will result in a period of transition during which present installations may be utilized while the requisite new developments are gradually brought into action.

City-gas of the Future.—With American cities served at present by carburetted water-gas, coal-gas, oil-gas, and coke-oven gas, not

to mention a declining supply of natural gas, it appears inevitable that those processes dependent upon oil must inevitably give way in favor of other established methods or new processes.

One of the cheapest and most efficient methods already established for manufacturing gas is the generation of straight water-gas from coke or anthracite coal. This yields a relatively dilute gas of about 300 B.t.u., which consequently cannot be used under existing standards, without being enriched with gas made from gas oil. Coal-gas is manufactured in many cities, but while this type of gas is of requisite concentration to meet existing standards, its installation is costly and it yields a large output of coke which must be disposed of as fuel; gas-house coke has not proved to be a wholly satisfactory fuel and its sale has not been altogether regular or profitable. In some municipalities the coke from the coal-gas retorts is used in turn as generator fuel in water-gas sets, the resulting water-gas being mixed with the coal-gas to yield a gas of about 350–450 B.t.u., which is then raised to the desired heating-value by the admixture of oil-gas. The production of this mixed gas is the most economical established procedure under the majority of conditions to-day. The process is also aided by the recovery of some of the by-product values in the coal-gas retorts.

Considerable improvements are immediately possible in the manufacture of mixed gas, through the combination of the coal-gas and water-gas generation into practically a continuous process, which will yield much better heat economy and hence lower operating costs than now prevalent. At the same time, as B.t.u. standards are lowered, a decreasing quantity of oil may be employed in the enrichment, until the use of gas oil is done away with entirely, approximately a 400 B.t.u. gas being the end-product then distributed. Such a gas is an ultimate, rather than an immediate, desideratum, since its use would entail modifications in existing appliances and methods of distribution. The economic pressure already in evidence will inevitably force developments into this channel, which admits not only of the fullest use of present installations and equipment but also is nearest in line with the stable source of fuel supply.

The whole field of development in respect to gas has been relatively stagnant, but once the barrier of an outworn thermal standard is broken down and the inertia that has always characterized the gas situation is supplanted by a vigorous sense of the latent possibilities in gas, substantial progress may be expected. The field of city-gas enmeshes closely with the undeveloped possibilities of gas in respect to industrial heating and even power application; and once the production of city-gas is placed upon a low-cost basis, soundly

grounded in the complete gasification of bituminous coal, and proper attention is accorded the efficiency of utilization, the full possibilities of this mobile form of energy may begin to be realized, with incalculable benefit to all concerned. In all progressive municipalities gas must eventually largely supersede raw coal in the homes and factories; not until then may the city-gas problem be regarded as solved.[1]

[1] For a further discussion of the potentialities of gas, see Gilbert and Pogue, America's Power Resources, New York, 1921, pp. 184–213.

CHAPTER XXIV

INTERNATIONAL ASPECTS OF PETROLEUM

UNTIL a few years ago the oil deposits of the United States were generally regarded as ample to supply her needs. The production of crude petroleum, indeed, increased so rapidly that organized effort was directed mainly toward enlarging the domestic demand and finding additional outlets abroad. Once fairly under way, however, the demands for the products of petroleum have expanded at a geometric rate until the problem of finding a sufficient volume of raw material to meet future requirements is of paramount importance. Within a short space of time, there has been a reversal from a situation in which production was forcing new outlets to one in which an insistent demand is seeking assurance of an adequate supply.

Two factors have accentuated this change. The war brought petroleum to the front as a necessity of the first rank; and a realization of a limitation in supply has come into account. The inability of the domestic petroleum resource to meet fully the responsibility which it has engendered is directing attention in growing measure to foreign sources of supplemental supply. Thus the United States is projected into the international struggle for oil and is facing a new range of complications in this field.

Political and Commercial Control of Oil Production.—The oil production of the world [1] may be classified according to the nationalities exercising political control of the productive areas or according to the commercial interests directing their exploitation. During the war the U. S. Bureau of Mines analyzed the mineral resources of the world in these two respects,[2] and the results for petroleum are shown in Fig. 145 and Table 120.

It is apparent from Fig. 145 and Table 120 that in 1917 the United States exercised political (or territorial) control over 67 per cent of the petroleum produced throughout the world, and commercial

[1] See pp. 52–53 for statistics on the world's production.

[2] The results of this investigation were published by J. E. Spurr, Political and Commercial Geology and the World's Mineral Resources, New York, 1920. Chapter I, on petroleum, is by John D. Northrop.

(financial) control over a slightly greater part, 72 per cent. Proportions of substantially the same order of magnitude obtain for 1920.

TABLE 120.—POLITICAL AND COMMERCIAL CONTROL OF THE WORLD'S OUTPUT OF PETROLEUM IN 1917

(After John D. Northrop)

Country	Production, Millions of Barrels	Country Exercising Political Control	Nationality of Dominant Commercial Interest	Approximate Extent of Control by Dominant Interests, Per Cent
United States	335	United States	United States	96
Russia	69.0	Russia	British-Dutch	40
Mexico	55.3	Mexico	United States	65
Dutch East Indies	12.9	Holland	British-Dutch	100
India	8.08	Great Britain	Great Britain	100
Persia	6.86	Persia	Great Britain	100
Galicia	5.97	Poland (?)	Germany	100
Japan and Formosa	2.90	Japan	Japan	100
Rumania	2.68	Rumania	British-Dutch	36
Peru	2.53	Peru	United States	70
Trinidad	1.60	Great Britain	Great Britain	80
Argentina	1.14	Argentina	Argentina	100
Others	3.04	Miscellaneous	Miscellaneous	...
Total	507	United States	United States	72

Political and Commercial Control of Oil Reserves.—The control of oil reserves is an entirely different matter from the control of oil production, although the two have not been clearly distinguished in all discussions of the matter. During the past few years, profound changes have been made in the political and commercial map of the world, and while many of these changes are still in doubt and hence to be spoken of with due reservation, there is an unmistakable correlation to be observed between the territorial adjustments and the unmined supplies of petroleum. (See Fig. 146.)

While the petroleum reserves outside the United States are still unmeasured, except in a provisional manner, the available evidence tends to indicate that approximately seven-eighths of the petroleum remaining to be produced in the world lies outside the boundaries of this country. In other word, though exercising territorial command of over two-thirds of the world's *actual* production of petroleum, this

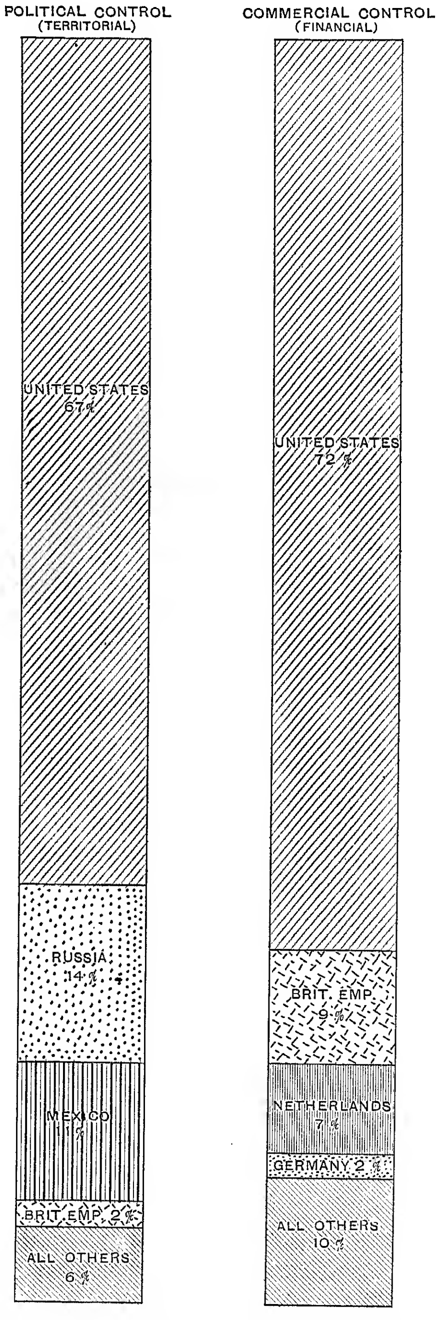


FIG. 145.—Political and commercial control of the world's production of crude petroleum in 1917; after Spurr and Northrop.

country possesses political control over only something like one-eighth of the resource. In the face of this circumstance, and in view of the fact that the United States consumes over half of the petroleum products turned out and supplies over three-quarters of the world's requirements in respect to these commodities, the American petroleum industry is seeking to extend its commercial control in foreign fields.

On page 24, Fig. 6, is a map of the world, compiled by the U. S. Geological Survey, showing the location and estimated size of the petroleum reserves of the world, together with an indication of some of the broad features of political control obtaining at the time the map was prepared in 1919. The map brings out the concentration of the oil reserves in five regions: the United States, the area bordering the Caribbean Sea, the region adjacent to the Caspian Sea, the Far East, and southern South America. The map affords an interesting key to many of the recent moves in the game of world politics.

New Problems in Petroleum Exploitation. — In extending commercial ac-

tivities into foreign territories, the American petroleum interests are encountering two problems of outstanding importance, new to the exploitation of petroleum in this country. These are: A tendency toward the nationalization of the petroleum resource, especially marked among the smaller independent countries, particularly in the Caribbean area and in southern South America; and keen international rivalry in the Old World on the part of the industrial powers, with the situation already far advanced toward

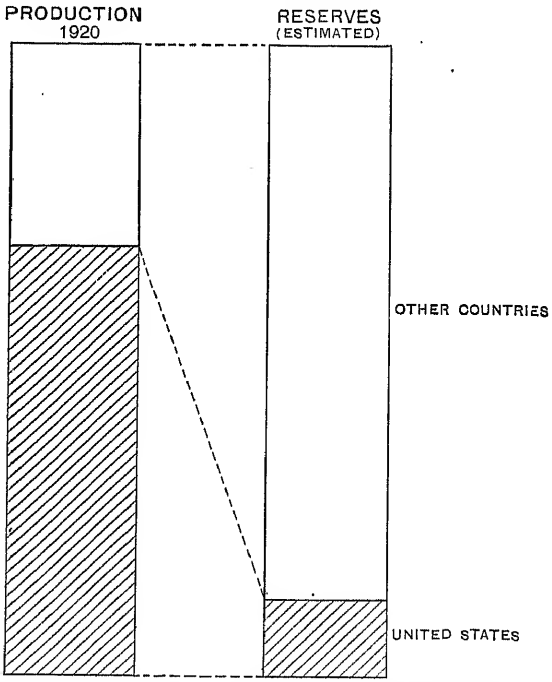


FIG. 146.—Chart showing the proportions of the world's production and reserves of crude petroleum in the territory controlled politically by the United States.

an exclusive understanding and a division into definite spheres of influence. Throughout both fields there runs as well the keen commercial rivalry common to business enterprise.

The Problem of Nationalization.—The Latin-American countries, in which the ownership of the natural resources in the colonial days was vested in the crown, are showing a growing tendency to retain and even reinstate the petroleum rights under the sovereignty of the nation. Of the Latin-American countries—the states coming under the sphere of the Monroe Doctrine—ownership of the oil in the

ground rests in the government in Bolivia, Costa Rica, and Venezuela, and in part in Argentina, Colombia, and Ecuador; while movements further to vest oil rights in the state are in progress in Colombia, the Dominican Republic, and Mexico.[1] This policy in Mexico has naturally attracted the widest notice, because of the extensive petroleum developments in that country; the new constitution of 1917, with its famous Article 27 declaring "in the nation is vested direct ownership of all minerals, petroleum, and hydrocarbons," and arousing the fear of its retroactive application, has already become a point at issue between the foreign operators and the Mexican Government.

The extent to which this movement toward nationalization of the petroleum reserves will go cannot be foreseen, but the consequences will undoubtedly be in the direction of limiting the degree to which outside commercial control may be gained and slowing down the rate at which the resources may be developed.

National ownership of the oil in the ground is not confined, of course, to the Latin-American countries, being true in varying degree of France, the United Kingdom, the British Colonies, Slovakia, and Russia.

The Problem of International Rivalry.—Oil has become so essential to modern civilization that other industrial nations are aggressively seeking both commercial and political control over oil-bearing territories. Efforts toward enlarging political control have apparently been confined to the Eastern Hemisphere, though commercial activities have been extended over the entire world, especially by British, Dutch, and French interests. In some directions, the political and commercial efforts have joined hands. The Government of Great Britain, for example, "has established a petroleum administration; owns a controlling partnership with veto powers on the board of directors in the Anglo-Persian Oil Company, which controls the oil resources of the greater part of Persia; gives financial assistance to its nationals engaged in oil development and is in every possible way promoting the acquisition by companies under British control or companies exclusively British, of oil reserves in all countries, including our own."[2]

Petroleum has also become involved in the administration of the mandate territories that grew out of the war. At San Remo in April, 1920, Great Britain and France negotiated an agreement "based on the principles of a cordial collaboration and reciprocity

[1] See David White, The Petroleum Resources of the World, Annals of the American Academy, May, 1920. See also Congressional Record, May 17, 1920.

[2] White, op. cit., p. 21.

when the petroleum interests of the nations can be negotiated to advantage," which agreement "may be extended to other countries by mutual consent," whereby the two countries party to the agreement would enjoy certain advantages in developing the petroleum resources of Rumania, Asia Minor, territories of the former Russian Empire, Galicia, the French colonies, and the colonies of the British Crown.[1] This Project of Agreement resulted in the interchange of notes between Great Britain and the United States, with special reference to Article 7 relating to Mesopotamia, the United States claiming equal oil privileges in mandate territory, with Great Britain maintaining that the San Remo agreement was based upon concessions granted to British nationals by the former Turkish government.

International rivalry for petroleum has led to restrictive legislation on the part of some countries favoring exploitation by their own nationals, and in this wise a new phase of nationalization has been projected into the problem.

The Significance of Ocean Shipping.—The advantages of fuel oil for ocean transportation and naval operations have undoubtedly played an important part in determining the policy of Great Britain in acquiring foreign reserves of petroleum, while these factors have also influenced the activities of the United States. The suggestion has also been advanced that the growing social consciousness of the coal-miners in Great Britain has been an added incentive for an active development of a petroleum supply. At any rate, the significance of oil in the maritime field is a sufficient explanation of the world-wide interest that has been taken in oil. The question, therefore, arises as to whether the world's supply of petroleum is sufficiently great to sustain automotive transportation on land, lubricate the wheels of industry and commerce, and support the revolution in ocean shipping to an oil-burning basis. It is by no means a foregone conclusion that the merchant marine of the world can count upon a supply of oil sufficiently cheap to sustain its operations for more than a relatively brief period of years.

There are approximately 55 million tons of steam shipping in the world, and roughly speaking its entire conversion to an oil-fired basis would require an annual consumption of over 500 million barrels of oil, or nearly the total quantity of petroleum produced in the world to-day. The unit consumption, of course, can be reduced considerably by the universal adoption of Diesel engines; but at best the oil consumption would still be of outstanding size.

The utilization of oil by ocean shipping, however, is limited more directly by the matter of price, and there are many reasons for

[1] See M. L. Requa, The Petroleum Problem, 1920, pp. 35–36.

believing that petroleum to date has been produced abnormally cheap, if not actually at a sub-economic level. Once the flush production of the richest deposits are exhausted and once the efficient utilization of the higher-rank petroleum products is gained, even ocean shipping may be forced largely to abandon the use of this product. Such possibilities seem to have been generally lost sight of, under the competitive spur of the advantages offered by oil at the present price-level. But whatever the future of oil, the fact remains that it is now definitely involved in competitive shipping efforts, and a growing use in this direction will probably be seen for some time at least.

Suggested Lines of Action.—It is thus apparent that petroleum has been projected into the international arena as an issue of the first magnitude. Eagerly sought as a source of national power and industrial advantage, the remaining supplies have come in for intense competition, complicated by nationalistic, socialistic, and imperialistic aspirations. As a result of these conditions, the American petroleum interests have met with restrictions in their efforts to extend commercial control into foreign fields.

Various suggestions have been offered with a view to enabling the commercial interests of the United States to participate more fully in the development of foreign oil-deposits. Among the lines of action advocated are: Direct government participation in the development work; governmental support to private enterprise; vigorous diplomatic action to secure an open-door policy and equality of opportunity to all nations; the use of economic pressure and retaliatory measures to gain this end; and many others. The suggestions have mainly been in the direction of invoking some degree of political support for the commercial enterprises concerned, with a view either to winning entire equality of opportunity or else, failing that, to bring to bear counter restrictions of an analogous character.

The Trend of the Situation.—The course of action likely to be followed by the major powers and the smaller nationalities in respect to petroleum cannot be foreseen, as this matter is involved in considerations of foreign and domestic policy that nowhere seems to be settled, complicated as the situation is by contending factions, conflicting interests, and divergent social theories.

The forces at play would seem to fall mainly into two catagories: the rivalry between Great Britain and the United States in seeking control of future supplies; and the perceptible tendency of the smaller independent countries to recognize the value of petroleum and restrict the exploitation of their internal deposits. As regards this whole matter, the widest diversity of statement has been given

publicity in all parts of the world, while a far-reaching diplomatic and commercial game has been played behind the scenes.

While the political outcome can only be guessed at, the economic result will undoubtedly be an intensive development of foreign fields, with the utilization of much of the output for some years to come mainly in the form of fuel oil. Barring international complications of a military nature, the oil production will presumably become available under the economic laws of commerce to all parts of the world where needed. The outstanding issue at present in the public eye seems to be the matter of political control, predicated in the last analysis upon commercial and military strategy; the greater need is for an efficient development and utilization of the remaining deposits in order that automotive transportation and industrial activity the world over may be sustained and developed.

Whatever happens, the United States faces the physical fact that the supply of crude petroleum available for her use cannot continue to increase volumetrically at the rate enjoyed up till now. The output of crude petroleum in the United States has virtually reached its maximum; the proven fields of Mexico are well-nigh exhausted, and a marked falling off in imports from that source is to be anticipated; even under the most favorable circumstances, deposits further afield can scarcely be developed into major producers under five to ten years. Cheap and bountiful supplies of crude petroleum will soon be a thing of the past. The answer to the domestic petroleum problem does not lie exclusively abroad; efficiency in production and utilization and supplemental sources of supply at home must share with foreign contributions the responsibility of sustaining those activities exclusively dependent upon liquid fuel.

CHAPTER XXV

MEXICO AS A SOURCE OF PETROLEUM

THE unique occurrence of petroleum in Mexico has resulted in a rapid and sensational depletion of the resource, and a widespread misconception as to the extent and future of its deposits. The concentration of the proven oil in a restricted area and its ready susceptibility to extraction have stimulated an intensive campaign of development, which has succeeded in bringing the known supplies to the verge of exhaustion while at the same time lending a false sense of confidence in the magnitude of the proven reserve. The realization of the true situation is likely to come as a startling climax to a period of flush production, like the termination of the meteoric career of a single well. For, in the words of a recent speaker, "No pump has ever profaned the casing of any Mexican well. These wells are born into the full virility of their gigantic powers. They live like giants, straining at the chains that bind them, and they die as giants should, stricken as by a thunderbolt."

Since oil was commercially developed in 1901, the production of Mexico has grown until that country has become second only to the United States in its contribution to the world's supply. First a substantial exporter of petroleum in 1911, Mexico in 1920 shipped 112 million barrels of petroleum to the United States, and 41 million barrels to other countries—28 per cent of the world's entire output in that year. Already the United States is dependent upon Mexico for a fifth of her petroleum requirements. The position of Mexico is shown graphically in Fig. 147 and statistically in the following table (Table 121).

The Oil-fields of Mexico.—Commercially productive deposits of petroleum are found in a narrow strip of territory in the Gulf coastal plain a few miles inland from Tampico and Tuxpam. This highly restricted area is responsible for practically the entire output of Mexican petroleum to date, and is the region to which reference is generally had when Mexican petroleum is referred to. This productive area is divided into two fields: the Northern, or Panuco, field, producing a heavy, viscous petroleum of 10°–13° Baumé gravity; and the Southern, or Light Oil, field, producing a lighter

petroleum of 19°–22° Baumé gravity, more suitable for refining than the heavy crude of the Northern field. The Northern field comprises three pools: Ebano, Panuco, and Topila. The Southern field is a narrow, sickle-shaped area, about 40 miles long and half a mile broad, containing the following pools from north to south: Dos Bocas; Tepetate-Casiano-Chinampa; Amatlan-Naranjos-Zacamixtle; Toteco-Cerro Azul; Alazan-Potrero del Llano; Tierra Blanca; Alamo; and Molino. The approximate location of the various pools is shown in Fig. 148. Up to June 1, 1921, the Northern Field had produced 152 million barrels, and the Southern Field had produced 492 million; while the current daily production was 130,500 barrels and 395,500 barrels respectively.

Table 121.—Comparative Production of Petroleum in Mexico

(In millions of barrels)

Year	World's Production	U. S. Production	Mexican Production	Mexican Exports to U. S.	Total Mexican Exports
1901	167	69.4	0.01	....	....
1902	182	88.8	0.04	....	....
1903	195	100	0.08	....	....
1904	218	117	0.13	....	....
1905	215	135	0.25	....	....
1906	213	126	0.50	....	....
1907	264	166	1.01	....	....
1908	286	179	3.93	....	....
1909	299	183	2.71	....	....
1910	328	210	3.63	....	....
1911	344	220	12.6	....	0.89
1912	352	223	16.6	7.38	7.62
1913	384	248	25.7	17.8	20.9
1914	404	266	26.2	16.2	22.9
1915	428	281	32.9	17.5	24.3
1916	461	301	40.5	20.1	26.7
1917	507	335	55.3	29.9	42.5
1918	515	356	63.8	40.8	51.8
1919	558	378	92.4	57.6	77.7
1920	688	443	163	112	153

Outside of the territory described above, there are many areas which will doubtless become commercially productive in time, but such fields must first be prospected and developed. A clear dis-

tinction should be drawn between the proven oil-pools already approaching exhaustion, and the undiscovered and the undeveloped fields of the Republic, which have a significance that the future alone can disclose.

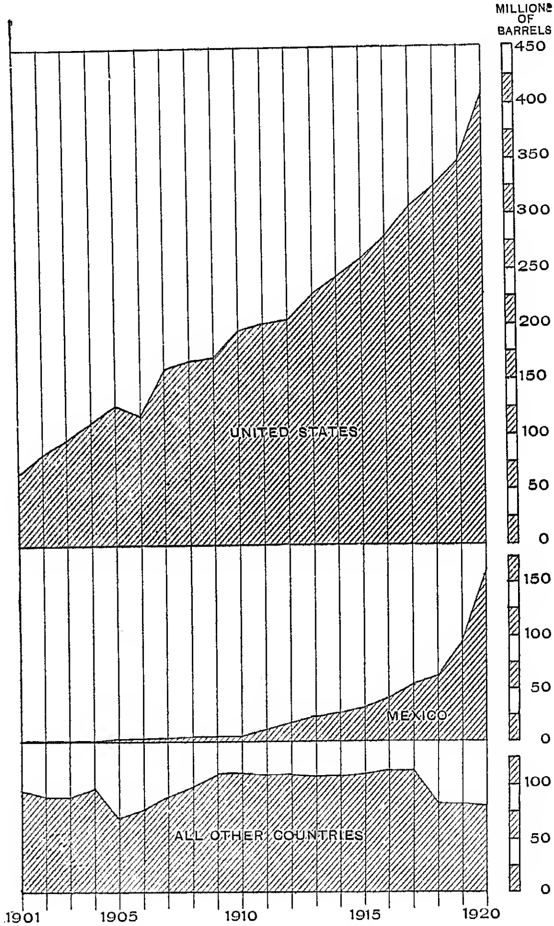


FIG. 147.—Production of crude petroleum in Mexico compared with the United States and all other countries by years, 1901–1920.

Occurrence of Petroleum in Mexico.—In the Tampico-Tuxpam region petroleum occurs under highly specialized geological conditions without parallel elsewhere. The oil exists in cavernous reservoirs "under such conditions of enormous pressure, unrestricted mobility, and easy availability, as to enable its entire withdrawal from any of the important pools within a few months under the intensive

development campaign which has raged . . . in the Mexican field." The important pools are found to contain from 100 to 150 million barrels of oil each; from the Los Naranjos pool in 1920 was taken 95 million barrels, or two-thirds of its probable total content.

The conditions of occurrence give rise to the largest producing wells in the world's history, both as to the volume of daily yield and

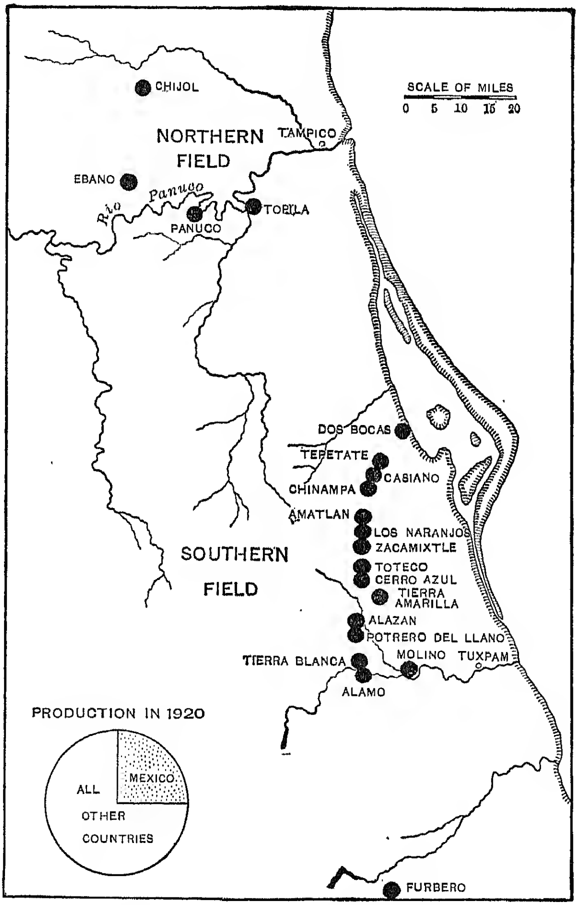


FIG. 148.—Sketch map showing the location of the most important proven oil pools of Mexico. Many of the pools shown are extinct. (See text.)

the total quantity produced. The Mexican wells have also displayed the peculiarity, unknown in the United States, of continuing to yield by their own pressure in undiminished volume so long as the flow of oil lasts. As in the oil-fields of the United States, the end of production comes through the inflow of water. But whereas in the

United States the water may be edge water, bottom water, or top water; in Mexico, it is bottom water upon which the oil floats under hydrostatic pressure.

The size of the Mexican wells has led to optimistic assumptions as to the size of the resource. "The gusher condition in Mexico seems to indicate ease in exploiting, rather than such abnormally large pools as have been inferred from the great size of the gushers encountered."[1]

In the United States, oil is found in a large number of widely separated pools, occurring in porous reservoir rocks under such conditions of pressure, mobility, and availability as to preclude its withdrawal except over a period of years, ranging up to forty years, but averaging perhaps fifteen years. The output of an oil-pool in the United States will consequently display a gradual diminution in volume. In Mexico, the crowding of the productive pools into an exceedingly small area—all the important pools with the exception of the Panuco group occurring in one long narrow structure—and the concentration of the oil in each pool into an interconnecting series of cavernous openings under hydrostatic head, give rise to an immediate and sensational yield once the concentration is tapped. A production that in the United States would be gained through the agency of a thousand wells is achieved under Mexican conditions by a half dozen wells, or even a single well. This contrast is the key to the situation. It is clearly shown in the tabulation following:

TABLE 122.—COMPARISON BETWEEN THE PRODUCTION OF PETROLEUM IN MEXICO AND THE UNITED STATES AT THE END OF 1920

(After Ralph Arnold)

Country	Proven Producing Area, Sq. Mi.	Production 1920, Millions of Barrels	Number Producing Wells, 1920	Average Daily Production per well, 1920, Barrels	Proven Oil Reserve, Millions of Barrels
Mexico..........	25	163	200	2600	300–400
United States....	4500	443	258,600	4.9	6000*

* From U. S. Geological Survey.

The Salt Water Encroachment.—A normal oil-field, such as those of the United States, enjoys a brief period of flush production, followed by a period of settled production as the area is being drilled up, in turn succeeded by a long period of slow decline as the output of the individual wells gradually dwindles. The abnormal oil-field of the

[1] E. De Golyer, Mexico as a Source of Petroleum and Its Products, Society of Automotive Engineers, Feb., 1919, p. 2.

Tampico-Tuxpam region in Mexico is displaying the wholly distinctive characteristic of an accelerating output to the verge of exhaustion—its period of rapid, flush production will represent the major event in its history. Its decline is likely to be sudden and spectacular, like the end of the individual well.

The salt water, which underlies the oil and supplies the hydraulic pressure, is rapidly drowning out both the Northern and Southern fields of the Tampico-Tuxpam area. The Dos Bocas, Tepetate, Casiano, Chinampa, and Potrero del Llano pools in the Southern Field were extinct at the beginning of 1921. During the early months of 1921, the Los Naranjos, Panuco, and Alamo pools were rapidly going to salt water. In August, the Amatlan pool became seriously affected. According to Arnold, "Panuco and Ebano apparently will continue for many years producing enough oil and a valuable mixture of oil and water to have an important bearing on the productivity of Mexico. This leaves Zacamixtle, a practically virgin pool, and Cerro Azul, a partly exhausted pool, the latter controlled by a single company, to furnish, with Panuco, the bulk of the proven future supply."[1] Since Arnold's analysis was made, a small pool, the Tierra Blanca, with an estimated reserve of 50 million barrels, has been brought in near the southern extremity of the Southern Field.[2] (See Fig. 148.)

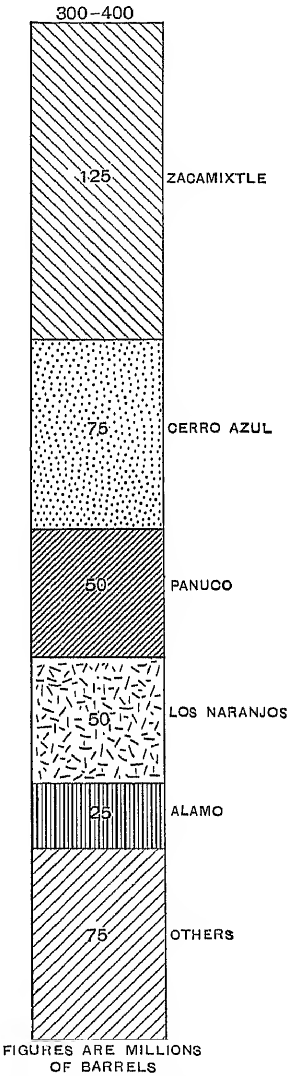


FIG. 149.—Estimated unmined supply of crude petroleum in the proven oil-pools of Mexico on Jan. 1, 1921; data in part from Arnold.

The Unmined Reserve.—The oil resources of Mexico, as previously noted, are represented by the *proven* area of the Tampico-Tuxpam region, and un-

[1] Ralph Arnold, The oil situation, Mining and Metallurgy, March, 1921, pp. 20–21.

[2] See L. G. Huntley and Stirling Huntley, Mexican oil fields, Mining and Metallurgy, Sept., 1921, pp. 27–32.

developed territory in other parts of the country. The reserve available in the *proven* area at the beginning of 1921 was estimated by Arnold to approximate 300 to 400 million barrels. The allotment of this reserve to the unexhausted pools is shown in Fig. 149. Estimates by other geologists differ in detail from Arnold's figures, but give the same order of magnitude for the oil definitely in sight.[1] Outside of the proven area, there is as yet no substantial basis for estimating the probable underground supply of petroleum; considerable prospective territory is known and development work will doubtless bring other pools and fields into action.

The output of Mexican petroleum is probably due for a slowing down in the period immediately ahead. If the rate of production of early 1921 is sustained, 1922 may see the end of the proven big fields of Mexico. On the other hand, special conditions may lead to a reduced rate of output earlier and a consequent spread of the remaining supply over a period of years. In either event, new productive pools, either in the Tampico-Tuxpam area or elsewhere in Mexico, can scarcely be developed with sufficient celerity to maintain an unbroken increase in that country's production of petroleum.

Character of Mexican Petroleum.[2]—Most of the light crude produced in the Southern field is topped, with the production of about 12 per cent gasoline, 5 per cent kerosene, 81 per cent fuel oil, and 2 per cent loss. Some of this oil, however, is completely refined, yielding 15 per cent gasoline, 7 per cent kerosene, 28 per cent gas oil, 25 per cent light lubricating distillate, 10 per cent heavy lubricating distillate, and 15 per cent gas and coke.

The heavy crude of the Northern field contains so little gasoline that its flash point is low enough to permit its use as fuel oil without

[1] Huntley and Huntley (Mining and Metallurgy, Sept., 1921, p. 30) give the following estimate of the known reserves:

	Barrels
Amatlan-Zacamixtle	50,000,000
Cerro Azul-Toteco	150,000,000
Tierra Blanca	50,000,000
Panuco River pools (have not been limited and seem capable of considerable extension).	?
Total	250,000,000

"These amounts disregard later recoveries from the same areas through stripping wells, as the factor used in the calculations was derived from the data in the Tepetate-Chinampa area, which excludes later recoveries."

[2] See G. A. Burrell, Oil & Gas Journal, January 30, 1920, p. 66.

refining. When topped, this crude yields 3.5 per cent gasoline, 4 per cent kerosene, 90.5 per cent fuel oil, and 2 per cent loss; the fuel oil fraction so obtained, however, is so viscous that only about 2.5–3 per cent gasoline is usually removed. Upon more complete refining, the heavy Mexican crude can be made to yield 3.5 per cent gasoline, 4.5 per cent kerosene, 17 per cent gas oil, 5 per cent lubricating oil, 65 per cent asphalt, and 5 per cent loss.

Typical yields from Mexican crude are shown in Fig. 150.

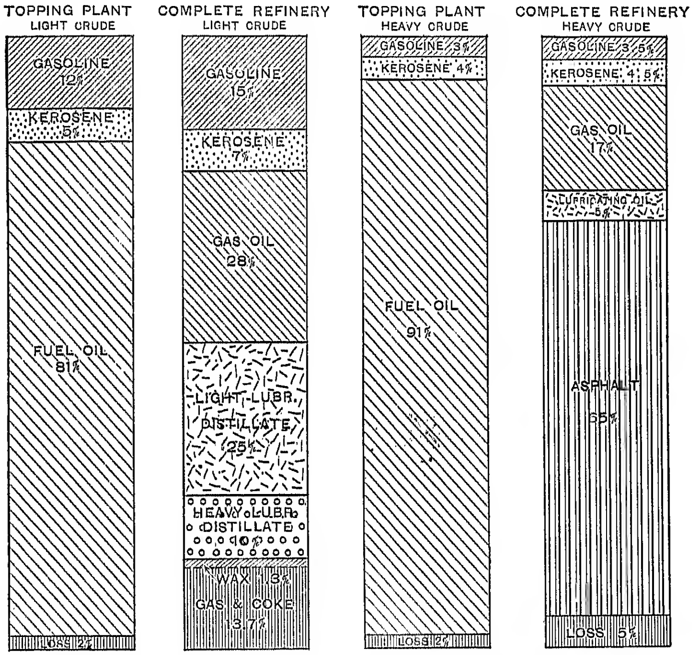


Fig. 150.—Chart showing the average yields from Mexican petroleum; data from G. A. Burrell.

Mexican Laws Affecting Oil Development.[1]—Wide publicity has been given the Mexican laws affecting oil development, and many conflicting statements are to be found on this subject. The mining laws of 1884, 1892 and 1909, based on the Constitution of 1857, "recognized the principle that the exclusive ownership of the petroleum deposits was vested in the owner of the land,"[1] and provided for the acquisition of petroleum rights by foreign companies.

In 1917 a new constitution was promulgated, based on the old land laws, which made a radical change in the petroleum legislation

[1] See The Petroleum Industry in Mexico, Commerce Reports, September 13, 1920, p. 1224.

of the Republic. As Article 27 of this constitution has met with active objection on the part of some of the foreign interests, a portion of the famous article is accordingly given below, following the translation published by the Latin-American Division of the U. S. Bureau of Foreign and Domestic Commerce:

TRANSLATION OF A PART OF ARTICLE 27 OF THE MEXICAN CONSTITUTION

The ownership of lands and waters within the limits of the national territory is vested originally in the nation, which has had and has the right to transmit title thereof to private persons, thereby constituting private property.

Private property shall not be expropriated except for cause of public utility and by means of indemnification.

The nation shall have at all times the right to impose on private property such limitations as the public interest may demand, as well as the right to regulate the development of natural resources, which are susceptible of appropriation, in order to conserve them and equitably to distribute the public wealth. In the nation is vested direct ownership of all minerals, petroleum, and hydrocarbons—solid, liquid, or gaseous.

Legal capacity to acquire ownership of lands and waters of the nation shall be governed by the following provisions:

1. Only Mexicans by birth or naturalization and Mexican companies have the right to acquire ownership in lands, waters and their appurtenances, or to obtain concessions to develop mines, waters, or mineral fuels in the Republic of Mexico. The nation may grant the same right to foreigners, provided they agree before the department of foreign affairs to be considered Mexicans in respect to such property, and, accordingly, not to invoke the protection of their governments in respect to the same, under penalty in case of breach, of forfeiture to the nation of property so acquired. Within a zone of 100 kilometers (62.14 miles) from the frontiers and of 50 kilometers (31.07) miles from the seacoast no foreigner shall under any conditions acquire direct ownership of lands and waters.

Article 14 of the new constitution states: " No law shall be given retroactive effect to the prejudice of any person whatsoever." It is the contention of the Mexican Government that this constitutional provision will fully protect the companies already legitimately interested in the petroleum industry in Mexico.[1] Many of the companies, however, have objected to the provision of the new constitution, and the matter has been brought under diplomatic consideration by the two countries.

Taxation of Mexican Petroleum.[2]—Prior to May, 1917, the

[1] Commerce Reports, September 13, 1920, p. 26.

[2] For a scientific discussion of the taxation problem in respect to Mexican petroleum see V. R. Garfias, General Notes on the Production, Marine Trans-

exports of Mexican petroleum were taxed approximately 3.9 U. S. cents per barrel. From May, 1917, to July, 1921, a so-called stamp tax was levied upon outgoing oil by a decree established under President Carranza. The amount of this stamp tax was approximately as follows: heavy crude, 5 cents per barrel; light crude, 11 cents per barrel; fuel oil, 9 cents per barrel; and crude gasoline, 56 cents per barrel, or $1\frac{1}{3}$ cents per gallon. In addition to the stamp tax which applied exclusively to petroleum there were minor taxes common to all exports, such as bar dues running from $\frac{1}{2}$ to $\frac{3}{4}$ of a cent per barrel, and the Infalsificable, or paper redemption tax. These minor taxes for petroleum were small, compared with the stamp tax as given above.

On July 1, 1921, a special tax supplanted the stamp tax, which had been in force from May 1, 1917 to June 30, 1921. This special tax differed from the superseded stamp tax in two main particulars: the basis of valuation was changed from that of the values of Mexican oils in Mexican harbors to the basis of the average values of similar products in the United States, the Mexican Treasury establishing monthly basic figures; and the special tax was based upon volume rather than weight. On June 7, 1921, a presidential decree instituted an additional tax, an export tax on petroleum and its products, also to take effect upon July 1, 1921.[1] This tax was not *ad valorem*, but was fixed in amount. The total taxes applicable to exports of Mexican petroleum in July, 1921, are summarized in the following table:

TABLE 123.—TOTAL MEXICAN TAXES ON PETROLEUM AND ITS PRODUCTS IN FORCE IN JULY, 1921

Data from V. R. Garfias

(In U. S. cents per barrel)

		Special Tax	Infalsificable	Bar Dues	Export Tax	Total Taxes
Light crude,	20° Bé.	13.000	1.300	.740	19.873	34.913
Heavy crude,	12° Bé.	8.800	.880	.782	12.322	22.784
Fuel oil,	16° Bé.	11.558	1.156	.760	15.899	29.372
Crude gasoline,	56° Bé.	52.46	5.246	.597	74.723	133.026*

* In U. S. cents per gallon—3.1673.

portation and Taxation of Mexican Oils, Amer. Inst. Min. and Met. Eng., Pub. 1054, Feb., 1921. Also Additional Notes on the Taxtion of Mexican Petroleum. (Advance copy supplied author in Aug., 1921, by courtesy of V. R. Garfias.) The data following are based upon the papers of Garfias.

[1] The collection of the export tax was subsequently deferred until Dec. 1921.

CHAPTER XXVI

THE RELATION OF THE COAL INDUSTRY TO THE OIL INDUSTRY

Coal and Oil Now Competitors.—Under present conditions coal, the dominant solid fuel, and fuel oil, the major component of crude petroleum, are competitors. This competition has attracted wide interest, and in many quarters the belief has been expressed that serious inroads will be made upon the coal industry by virtue of the superior convenience and efficiency of oil fuel. As a matter of fact, however, petroleum cannot be expected to radically displace coal in industry and transportation, since a crude petroleum production of about 3 billion barrels per year would be necessary to drive coal from its present ascendancy.

Oil Becoming More Specialized.—Substitution of fuel oil for coal marks merely an era of crude overproduction in respect to balanced demands. For many years the oil-fields of the United States have supplied crude petroleum in excess of the higher requirements of the market, with the result that the surplus in the form of fuel oil was forced to find an outlet in competition with coal. For the future, however, fuel oil will represent a narrowing percentage of the crude petroleum mined, since the more specialized uses—automotive power, lubrication, chemical by-products—are coming into growing importance and are registering their claims ahead of the demand for industrial fuel. Not only has the rate of crude production in this country long been lagging behind the growth of these specialized demands, but the latter are due for further increases in the future, while the crude output has virtually reached its maximum. This cross-purpose relation between supply and demand, though latent in 1921, has created a problem which is now generally recognized. The current answer to this problem is reflected in the present activities in the direction of developing foreign oil-fields. The complete answer, however, goes much deeper and involves foreign developments linked with intensive research, both material and economic, for the creation of new technology. The latter aspect of the matter is yet uncultivated, and offers an outstanding opportunity for advance. Coal represents one of the most potent directions from which oil can gain relief from the limitations of a waning resource.

Coal Becoming More Generalized.—At the same time that oil is gradually becoming restricted to a highly specialized field of service, and is seeking new sources of raw material to cover even this latitude, coal is undergoing an evolution almost as rapid in an opposite direction. With no comparable resource limitation, coal is being forced by economic restrictions of a different order to seek new directions of application, with the correlative freeing of potential by-products which must find new outlets. Oil is seeking new sources of supply; coal is seeking new types of demand.

These two trends in conjunction bid fair to bear important fruit in the future. Changes in oil will require supporting resources. Changes in coal will require new outlets. In view of this circumstance, it is important to analyze the coal situation in regard to its imminent changes, and to appraise the bearing that these changes are likely to have upon the oil situation.

A Coal Refining Industry Developing.[1]—Just as the production of crude petroleum gave rise to a petroleum refining industry which has come to treat most of the crude petroleum produced, so likewise coal is attaching to itself a refining activity which will eventually involve a significant proportion of the crude coal mined, thus displacing raw coal with coal products. Progress toward a refining industry on the part of coal is generally conceded; the speed and character of the evolution only is open to question. The advance of petroleum in this direction was rapid, thanks to the insistent character of the demands created by the phenomenal growth of automotive transportation. The progress of coal in this direction has been slow, due to the large supply of raw material available, the presence of anthracite coal in the East, and the general neglect that has been accorded this whole matter. Coal refining, however, has already involved half of the coke industry and a small fraction of the manufactured-gas industry; or, in terms of bituminous coal produced, around 8 per cent is now refined before utilization.

There is much evidence to indicate that many conditions are shaping up—even outside the range of oil—which will accelerate changes in coal and bring important developments into view. These changes may be expected to take place first in the various sub-industries using raw coal, such as the coke industry, the gas industry, and the power-production industry.

The Coke Industry as a Source of Oil.—The refining of coal to date has taken place largely within the confines of the metallurgical coke industry. Roughly one-sixth of the bituminous coal produced

[1] For further details, consult Gilbert and Pogue, America's Power Resources, New York, 1921, pp. 184–213.

in this country is converted into coke and of this quantity approximately one-half is treated with by-product recovery, that is to say, refined. In connection with this by-product treatment which involves about 40 million tons of coal, around 13 million barrels of benzol, light oils, and tar are annually produced. The potential yield of the entire coke industry, therefore, once by-product practice has transgressed the whole field, is around 25 million barrels of oil products on the present basis of technology.

But it must be remembered that such yields of oil products arise incidentally from a process in which the focus is upon the production of coke. There are probabilities of strikingly increased yields of oil when it becomes important to force this phase of the output and requisite new technology is developed to this end.

The Gas Industry as a Source of Oil.—The gas industry, as now constituted, is an insignificant source of oil products, since this industry consumes only about 5 million tons of bituminous coal, slightly more than 1 per cent of the country's total consumption. There are potentialities of importance attached to the gas industry, however, in the possibility of its expansion to serve the fuel needs of communities, in the necessity of its growth to replace the waning supply of natural gas, and in connection with coal-mine generation of power which may develop in part along lines of by-product gasification. Such changes, moreover, may be forced rather rapidly by the rising prices of coal, the increasing dirtiness of cities lacking smokeless fuel, not to mention the growing needs for the oil by-products which will thus be made available. It is advisable, therefore, to take a rough measure of what these potentialities hold forth in the way of augmenting the supply of oil.

Municipal Fuel Plants a Coming Development.—It is technically feasible for the gas industry, which now supplies a small part of the community's requirements, to expand to the point of filling the total fuel needs of the community. Developments of this nature, in fact, are already afoot and are progressing more rapidly than is generally appreciated; the movement will be greatly facilitated upon a public and municipal awakening to the real possibilities of the matter.

At present around 300 million tons of bituminous coal are used for domestic and industrial purposes. Assuming that one-third of this portion is utilized in populous centers, by-product gasification of this portion under present technology will yield around 25 million barrels of oil products. New technology holds the possibility of expanding this output to 50–100 million barrels.

It is thus seen that a proper utilization of coal in our cities, which is bound to come, holds the possibility of contributing a highly

significant quantity of crude oils for the use of the oil-refining industry.

Effects of Waning Natural Gas Supply.—The United States at present is consuming around 600 billion cubic feet of natural gas, largely in the populous region of Indiana, Ohio, West Virginia, Pennsylvania, and Western New York. A tremendous investment in capital and equipment has been provided to meet this function. The supply of natural gas is conspicuously on the wane, and if the investment in the natural gas industry is not to be lost, artificial gas must be developed to supplement the natural-gas supply. In point of fact, the replacement of natural gas by artificial gas is rapidly taking place. There is a conspicuous trend in the natural-gas industry for the upgrowth of coal gasification plants, and this tendency may be expected to increase in the future. This whole trend ties in with the possible upgrowth of municipal fuel plants, and in itself forms an important accelerating motive for the rapid development of by-product gasification of coal. It may be noted further that certain oil companies involved now in the production of natural gas will inevitably find themselves engaged more and more in the by-product utilization of coal, thus bridging the gap which now intervenes between coal and oil.

Centralized Power Plants.—The burden that coal imposes upon the railroads of the country (over one-third of our freight is coal) and the inability of our industries to expand rapidly, or beyond certain limits, under this burden, are two factors that are forcing a steady drift toward central power plants near the mine mouth for the extraction of energy from coal. The initial tendency in this direction of course derives its pattern from the hydroelectric development, and coal-field generation of electricity is already a reality.

There are serious economic obstacles, however, to the centralized conversion of coal into electric power through the medium of steam, involved in the loss of the exhaust heat (made use of in distributive plants) and the failure to recover the by-products. These two objections, tempered somewhat by the course of balance between the efficiency of the steam turbine and the large gas-engine installation, will force more and more consideration to by-product gasification of the coal as the intermediate step in the energy extraction. As this gasification step gains ground in engineering and economic practice, aided by the growing technology stimulated by the needs of the municipal fuel plant, the ultimate procedure of gas transmission as an alternative to electric transmission will come into being. Already in fact, some engineers are inclined to see under some conditions greater ultimate economy in this direction than in connection with

the electric transmission of power. This whole matter links significantly with the needs of the natural gas situation, the two together forming a strong probability that eventually this country will see a more extensive network of gas transmission lines than is now characteristic of the territories served by natural gas.

Centralized power plants, which may develop rather quickly in response to the needs of transportation, if for no other reason, may come to involve as much as 100 million tons of coal, giving the possibility of an additional oil supply of some 25 million barrels under present practice, with an eventuality of 50–100 million barrels under new technology.

While quantitative estimates of the kind noted above are subject to many uncertainties it is apparent that there are three developments under way within the coal situation, each of which holds some promise of contributing oil products to the maximum of 50–100 million barrels, or a total of 150–300 million barrels. With all due qualifications in mind, it is apparent that such potentialities are sufficiently significant to be accorded serious attention.

The Solution of the Peak-load Problem.—One of the most perplexing problems in the way of cheap and efficient heat and power is the variable and seasonal character of demand, requiring excess equipment to care for the peak load. Such is notoriously the case in public utility plants and central power stations, and few subjects have received more attention from engineers than this matter. The possibilities of a technological process that will permit a variable proportion of oil and gas to be made from coal would be so great in the direction of solving the peak-loak problem as to give an accelerating impetus to the municipal fuel plant, the central power plant, and the whole matter of by-product gasification of coal. So great is the need for such an outcome that this development may be ultimately expected. A process otherwise economically sound, which has the added advantage of meeting the peak-load issue, would have value so outstandingly obvious as to require no additional emphasis.

Oil from Coal Versus Oil from Shale.—An economic analysis of the coal industry, with reference to the changes that are coming, leads to the conclusion that oils from coal may rank in importance with shale oil. In many respects, coal deposits hold greater immediate possibilities than do the bulk of the shale deposits.

Oil-shale is oil-forming material diffused through clay. Coal is oil-forming material diffused through carbon. The richest oil-shales occur in the West. Coal, on the other hand, is found in the heart of our populous industrial section; in fact, our populous industrial

section is such because of the presence of coal. Oil-shale has the possibility of yielding a barrel of oil and 20–30 pounds of ammonium sulphate per ton of shale, the residue being for the most part worthless. Coal has the possibility of yielding upwards of a barrel of oil and 20–30 pounds of ammonium sulphate per ton of raw material, the residue being fuel more valuable than the raw coal.

Solid Fuel Ultimately Obsolete as a Dominant Form.—Fuel in liquid and gaseous form holds such advantages in the way of convenience and efficiency that the use of solid fuel may be expected to be gradually relegated to second place.[1] The tendency will be to convert more and more of the raw coal produced into gas and oils along the lines laid down above. As the matter now stands, the utilization of raw coal is so ill-fitted to the needs of modern industrialism that the changes outlined are bound to come in growing degree.

The crude petroleum situation requires supplementary resources. Foreign supplies are unable fully to meet this need. Attention is consequently already focusing upon domestic supplements. Oil products from coal represent a raw material source of great future importance. Developments coming in the coal industry hold the possibility of contributing highly significant quantities of oil products, and the coal resources of the country represent a source of oil that will yield a rich reward upon proper cultivation.

[1] For a discussion of form value see: C. G. Gilbert and J. E. Pogue., Form Value of Energy in Relation to Its Production, Transportation, and Application, Jour. Am. Soc. Mech. Eng., January, 1921, pp. 26–28.

CHAPTER XXVII

OIL-SHALE

Before petroleum was discovered in the United States, a small quantity of oil was produced by the distillation of a volatile type of bituminous coal called cannel. From the crude oil so obtained, a product suitable for illumination was manufactured. Thus there was a coal-oil industry in this country antedating the petroleum industry.

When flowing wells of petroleum were developed, the coal-refining industry found it impossible to compete with the natural product; and it was not long before the petroleum industry held undisputed sway in the production of liquid fuels. All that was left of the early commercial efforts to win oil from solid bituminous matter was the term coal-oil, which came to be erroneously applied to illuminating oils of petroleum origin, and is even so used to-day. The bounty of nature supplanted the ingenuity of man; the lavish flow of petroleum from the earth cut short the growth of coal-refining for over a half century.

Of late years, again, the production of oils from bituminous minerals has come to the fore, but this time the chief interest is focused upon bituminous shales, products which are related to the cannel coals but leaner in volatile, oil-forming components. The revival of the "rock-oil" industry is coming from a new and unexpected quarter. Work conducted by the U. S. Geological Survey in 1913 called attention to extensive shale-oil deposits in Colorado, Utah, and Wyoming, where hundreds of square miles were found to be underlain by beds of bituminous shale, much of it capable of yielding upon distillation upwards of 1 barrel of oil to the ton. Since that time, the growing inadequacy of domestic petroleum to support the demands it has created has been gradually turning commercial attention not only to the Rocky Mountain deposits but to oil-yielding shales and coals in many other parts of the country, but the industrial efforts in respect to these leaner sources of oil supply are still feeling their way in an attempt to sound the possibilities in the new directions. The whole movement has likewise been seized upon by pro-

moting and stock-selling undertakings and through these avenues the matter has been widely advertised to the general public.

Character of Oil-shales.—Oil-shales are dark-colored, sedimentary strata, consisting of a dense matrix of clay more or less saturated with organic materials resulting from the decomposition of plant and animal remains. Oil-shales vary considerably in the quantity of organic matter present, and with increasing proportions of the latter they grade into the cannel coals. Both the oil-shales and the cannel coals are distinguished by the presence of considerable hydrogen, which combines with the carbon upon the application of heat and hence enables these products to yield hydrocarbon oils resembling petroleum when they are subjected to distillation. Nitrogen is also present in variable quantity, yielding a valuable commodity when extracted but interposing difficulties in its recovery. The cannel coals, in turn, through a diminution in hydrogen content, grade into the bituminous coals. Thus, in a general sense, oil-shales are related to the coal-series, and may be regarded as hydrogen-rich semi-coals so diluted with mineral matter as to be without usefulness in their raw state as fuel.

Distribution of Oil-shales.—Lean bituminous shales are very common and widely distributed, but the richer varieties, like the cannel coals, are much more restricted in occurrence. Enormous tonnages of rich shale, in relatively thick beds underlying hundreds of square miles, occur in the Green River formation of northwestern Colorado, northeastern Utah, and southwestern Wyoming. These deposits have attracted considerable attention, and the richer and more accessible portions in Colorado and Utah have already been the scene of much activity in the private acquisition of territory and the establishment of experimental plants for the extraction of the oil. At Grand Valley and Debeque in Colorado, the efforts have been particularly active.

In many other parts of the West, but especially in Nevada, Montana, and California, deposits of oil-shales have been studied and experimental work done. At Elko, Nevada, a small-scale commercial shale-oil plant has been placed in operation, with a daily output of 100 barrels of crude oil.[1] In Montana oil-shales have been found in association with phosphate deposits.

Further east are extensive deposits of leaner oil-shales, underlying considerable portions of the states of Texas, Wisconsin, Indiana, Kentucky, Pennsylvania, and New York. In many localities in the East, the shales, while apparently leaner in oil-potentiality than the

[1] V. C. Alderson, The Oil-shale Industry in 1920, Combustion, March, 1921, p. 31.

Western deposits, enjoy an intimate association with other mineral deposits, such as coal beds, phosphate deposits, cement materials, limestones, and others, thus affording possibilities of a coordinated extraction of values.

Foreign Developments of Shale Oil.—The development of a domestic shale-oil industry has been stimulated by the commercial production of shale oil abroad, but the economic and technical peculiarities of the foreign activities have not apparently been fully apprehended in this country. The commercial success attained in Scotland has been generally drawn upon as a criterion of what may be accomplished in the United States.

The Scottish oil-shales differ from those in the United States by containing, roughly speaking, about half the oil and twice the recoverable nitrogen. In Scotland, therefore, the industry has been developed on the basis of nitrogen recovery, the oil being virtually a by-product. The Scottish technology has been strongly colored by this relation. The shale under Scotch practice is treated in vertical retorts, in the upper part of which the product is heated gently with the expulsion of the oil and in the lower part raised to much higher temperatures and treated with steam for the extraction of the nitrogen. The shale now retorted in Scotland yields about 25 gallons of oil and 36 pounds of ammonium sulphate to the ton.[1] The crude shale oil so obtained yields a somewhat similar range of products to those made from petroleum, but in different proportions and with a far higher percentage of loss. The percentage yield from one of the commercial plants in Scotland is shown in the table following:

TABLE 124.—PERCENTAGE YIELDS FROM CRUDE SHALE OIL IN A COMMERCIAL PLANT IN SCOTLAND

(Data from U. S. Bureau of Mines)

Products	Percentage Yield
Naphtha (gasoline)	9.9
Burning oil (kerosene)	24.7
Gas and fuel oil	24.4
Lubricating oil (low viscosity)	6.6
Wax	9.5
Loss (including still coke 2 per cent)	24.9
Total	100.0

[1] For a description of Scottish practice, see Gavin, Hill, and Perdew, Notes on the Oil-shale Industry, U. S. Bureau of Mines, 1919.

It will be observed that the gasoline recovery is low, the yield of lubricants is small and of the less desirable type (non-viscous), and the losses notably high.

The shale-oil industry in Scotland has achieved commercial success as a whole, but in its development the majority of the individual efforts met with financial failure, and only a few large, well-organized companies survived. At no time could the industry have been supported by the oil-yield alone, nor under the conditions of oil-prices that prevailed in the United States. The Scottish experience, both technical and economic, may be applied to conditions in this country only with the utmost caution.

Oil-shales are known in many other parts of the world, and some have received more or less commercial attention such as those in France and New Zealand, but nowhere outside of Scotland has a sustained industry developed.

American Development of Oil-shale.—During the past five years an oil-shale industry has been developing in the United States, but thus far the activity is still in its formative period, and no substantial output of oil has come upon the market. The difficulties, both technical and economic, in the way of such an upgrowth, under the stimulus of dissociated and opportunistic efforts, are indeed imposing. Progress is gradually being made, largely as a result of trial and error, but the outcome as yet is by no means clear. The technology requisite to the retorting of the American shales is still in an experimental stage, with a large number of partly developed processes in the field; while the refining of the resulting crude shale oil is still largely an unknown quantity. Again, the whole matter of handling and marketing the products, in order to bring them into the channels of trade, remains to be worked out.

On the other hand, the stimulus toward shale-oil production remains yet to be felt in its full intensity.[1] As soon as the supply of crude petroleum falls sufficiently short of requirements to bring a permanently higher price-level into the field, the economic opportunities for the profitable production of oil from shales and coals will be considerably enlarged at the same time that commercial enterprise will be brought to a more rigorous development of the whole matter of supplemental oils.

The Prospects Ahead.—From the point of view of those interested, or becoming interested, in the commercial exploitation of oil-shales, there is no question but that deposits of this substance in the aggregate represent an untapped reserve of crude oil very many

[1] See Gilbert and Pogue, The Energy Resources of the United States, Bull. 102, Vol. I, Smithsonian Institution, 1919, pp. 77–81.

times greater than the available supply of petroleum. There is no doubt, also, of the immediate desirability of supplementing the developed sources of petroleum supply with oils from new directions. Thus far there has been no economic room for commercially exploiting the leaner oil resources of the country, for oil requirements could be met by the flow of petroleum from domestic wells and such easily accessible foreign deposits as those of Mexico. The opportunity for such developments lying ahead would seem to be predicated upon the further course of imported petroleums, since domestic petroleum has already fallen short. If foreign petroleums are quickly and cheaply made available to the United States, the opportunity for leaner resources will be deferred for another period. But foreign oil deposits cannot apparently be quickly tapped nor so developed as to yield a sustained supply of crude petroleum to this country at anything approaching the price-level prevailing in the past. The development of supplemental oils would therefore seem to be an early necessity.

As to the precise course this development will follow, the answer is not so clear. Attention so far in this country has been largely confined to the possibilities of exploiting the Western shale deposits for the production of oil alone. The potentialities of the Central and Eastern shales in respect to the coordinate extraction of a range of values in addition to oil have been accorded subordinate attention, in spite too of the greater accessibility to markets enjoyed by these deposits. Likewise, the relationship of oil-shale to the cannel and other high-volatile coals (coals which have been termed gas-coals but which may come to be termed oil-coals), has not been adequately emphasized; nor the correlation of this matter with the low-grade, high-volatile lignites.

By-product Oils from Oil-shales and Oil-coals.—As the need for supplemental sources of oil becomes more insistent, industrial efforts will be redoubled and commercial results will be forthcoming. A growing output of crude oil will doubtless be realized from Western shale deposits, but by-product oils from Eastern shale-beds worked in conjunction with associated mineral values and from high-volatile coals and lignites subjected to refining may also be expected to come into growing, if not superior, prominence. In this event, the oil-shale industry as a whole will develop less along the lines of a distinctive single-product activity such as the production of crude petroleum now is, and more in the direction of a complex chemical industry, on the one hand involving the extraction of coordinate values with oil as a joint-product or even a by-product, and on the other hand merging with the output of by-products from the refining

of the oil-coals such as lignites, cannels, and the high-volatile bituminous coals.

At best, however, the attainment of substantial results involves an important consideration of time. The requisite efforts can scarcely be expected to be put forth until the exigencies of economic pressure force the issue. While such a time may not be far distant, new industries based upon new technology and a revolution in economic practice cannot grow with celerity to the magnitude required without the lapse of years, if not decades. In the meantime the oil-shales and the oil-coals as well will come increasingly under requisition, with the odds in favor of those activities proceeding with due regard to both the physical and chemical aspects of the principle of multiple production.

CHAPTER XXVIII

FULL UTILIZATION OF PETROLEUM

A VAST amount of discussion has been devoted to the prodigal manner in which the natural resources of the United States have been developed, and petroleum has come in for no small share of attention in this respect. The small proportion of the original oil in the ground that ultimately performs a useful service to society has frequently been pointed to as a measure of the wastefulness that characterized the exploitation of this resource. Just what constitutes waste, however, is an uncertain matter, depending very much upon what is assumed to be the criterion against which performance may be measured. American petroleum has been brought into service at a tremendous cost of the oil itself, but a rapid industrial growth and a low capital expenditure have been gained in return. We have paid in oil for the speed with which the present volume of production has been attained and for the relatively low level of prices we have enjoyed during that attainment. The magnitude of the expenditure may turn out to be a false economy, and many are already inclined to designate it so, but American economic practice elected this procedure and it is idle to speculate upon the desirability of results which cannot be changed.

The time has come, however, when the methods of the past can no longer be followed; the oil remaining is not sufficiently bountiful to support its use for other purposes than as a source of material energy and chemical products. The accumulating pressure in this direction is already indicated by the rapidly growing capital requirements of the petroleum industry. From now on, the tendency will be to use relatively less of the material itself, but to put greater effort in the service-value extracted from it.

The limitations in resource size are accordingly beginning to dictate a fuller utilization of petroleum, while at the same time calling attention to the methods that are available for stretching the remaining volume of supply over a greater area of service. Under the new conditions, therefore, a criterion of efficiency is afforded and it becomes a matter of practical importance to measure the existing slack which may be taken up between supply and demand before a true shortage intervenes.

The course of the oil supply depends upon the attainments in three

directions: the foreign output that may be developed or directed into the domestic market; the supplemental sources of supply that may be brought into action; and the degree to which the overall efficiency of petroleum may be increased. Growing attention will of necessity be devoted to all three avenues, for the utmost that may be expected from the combined effort will scarcely prove too much in view of the requirements of the future.

The outlook for foreign developments and supplemental sources of supply has been reviewed in previous chapters. The possibilities of improvement in respect to the production, transportation, refining, and utilization of petroleum may now be briefly appraised.

Efficiency of Production.—In the search for oil-bearing territory in the United States, much of the work of exploration is done by the individual wildcatter, who frequently sinks his well with inadequate justification of finding oil. Lacking in organization and engineering practice, this method leads to a notable waste of labor and materials, besides opening up new territory with inadequate adjustment to transportation facilities or market demand. The science of geology has multiplied by a large factor the chance of striking oil, but much of the work of exploration is still conducted without geological advice. It has been calculated by the president of one of the large Mid-Continent producing companies, from extensive records of the company, that 85 per cent of the wells located on the basis of careful geological surveys turned out to be productive, whereas only 5 per cent of the wells located at random were successful. Engineering exploration, now used almost exclusively in the search for foreign oil-pools, has a growing field of application in this country.

The development of the oil-bearing territory, following its location, is subject to conditions that usually lead to extensive underground losses. Most of the oil-field operations in the United States are conducted by large numbers of rival interests. The individualistic and highly competitive type of production thus induced is markedly different from that obtaining in most other mining operations, and is responsible for a racing, unorganized extraction of the oil which leads to a tremendous sacrifice of values. This kind of activity is especially characteristic of new fields where boom conditions and checkerboard holdings are prevalent. Under such conditions, an excessive number of wells are drilled resulting in needless expenditures amounting to millions of dollars; more or less uncoordinated drilling prevails, leading to uncontrolled underground movements of associated gas and water, with the loss of untold quantities of oil and natural gas which are thus put for all time beyond the reach of extraction; and finally, when the field is abandoned, over one-half

of the oil is left underground, still clinging to the pores of the oil sands.

For many years the U. S. Bureau of Mines has studied the vital problem of unrecovered oil, and has recently expressed the opinion that the best evidence seems to indicate that only from 10 to 20 per cent of the oil underground is now being recovered.[1] It is the belief of the engineers of the Bureau of Mines, based upon what has been accomplished in some of the older fields by water-flooding and by the use of compressed air, that after a field has been brought to the point of abandonment, we should often be able by improved methods to recover half as much oil again as was originally produced.

While the heaviest losses on the part of oil are sustained underground as the inevitable result of the destructive effects of competitive drilling of the field, losses due to inadequate methods of handling the product when it reaches the surface are far more sensational because open to observation. Surface losses are greatest in new fields and arise generally from the fact that production is forced in advance of preparations for handling and storing the output. As a result, some of the oil escapes any capture whatsoever, sinking into the earth or flowing down streams; great quantities of the lighter and more valuable components of the oil pass into the atmosphere through evaporation; while fires are responsible for another heavy toll of these valuable products. Even with adequate storage facilities, losses from evaporation are usually notable, and in many fields large quantities of residues and oil-water emulsions are made no use of whatsoever. Enormous volumes of natural gas are usually produced along with the oil, and in the absence of an adequate demand for this product, much of the output is allowed to escape into the atmosphere.

The Bureau of Mines has recently called attention to the magnitude of the losses resulting from the evaporation of gasoline from crude petroleum while in storage. Careful investigations have disclosed that in many cases 20 per cent of the gasoline content of the crude oil is being lost by evaporation before it reaches the refinery, and that probably one-half of this loss may be economically saved by more careful attention to conditions of storage and handling.

On the whole a low recovery factor characterizes the production of petroleum under the conditions that have prevailed in this country. Technical means are available for notably increasing the efficiency of extraction, but the handicap of competitive conditions working at cross purposes with the occurrence of oil still obtains. A funda-

[1] J. O. Lewis: Our Future Supplies of Petroleum Products; address before Independent Oil Men's Association Convention, Denver, September 29, 1920.

mental improvement in oil production may call for far-reaching changes in economic practice.

Efficiency in Transportation.—Crude petroleum is transported in the main through an extensive system of pipe-lines supplemented by coastwise movements in tank-steamers. This distinctive mode of transportation is an outstanding feature of the petroleum industry and represents a high attainment in respect to efficiency. Some losses of oil, however, take place through evaporation and leakage, approximating 1 per cent in the gathering lines and 1 per cent in the trunk lines, according to investigations made by the U. S. Bureau of Mines in the Mid-Continent Field. Lack of transportation facilities in newly developed territory is a potent cause of losses by necessitating the accumulation of oil in the field in excess of adequate storage facilities.

Petroleum products are shipped in bulk in tank-cars, and considerable evaporation losses take place in respect to the lighter products. In the most carefully built but non-insulated tank-car with dome cover and safety valve fitting tight and accurately, gasoline may evaporate to the extent of 5–6 per cent in a six-day trip in summer. An insulated tank-car has been developed to take care of this condition; its wider use would lead to notable economies, for the small losses assume imposing proportions when multiplied by the billions of gallons of volatile products affected.

Refinery Efficiency.—Petroleum refining, in general, falls short of the efficiency attained in many chemically controlled industries. Much of the crude run to stills is merely skimmed of its lighter components, all else being left as a residual fuel oil. The failure to fully refine even the bulk of the crude petroleum brought into use entails a tremendous economic loss, which grows out of a lack of balance between the several major demands and the crude supply. On the physical side, the segregation of the products is not sharply defined, so that in many cases a portion of the more valuable products are marketed with the less valuable. Statistics gathered by the U. S. Bureau of Mines for several years indicate that about 4 per cent of the oil run to stills is unrecovered in the form of products. Part of this loss is inevitable, but a portion may be eliminated by more efficient installations. Much of the loss represents gasoline vapor, and it has been estimated by the Bureau of Mines that recovery in this respect to the extent of 2 per cent of the crude produced could be attained.[1]

[1] E. W. Dean, Status of Refinery Practice with Regard to Gasoline Production, Society of Automotive Engineers, February 6, 1919.

Efficiency in the Utilization of Petroleum Products.—In the utilization of some of the products of petroleum there are losses arising from the inefficiency of the appliances involved which offer important fields for improvement. The most outstanding opportunity for increased efficiency in utilization applies to gasoline, which must be more effectively employed to meet the mounting requirements in this field. During the war the Bureau of Mines estimated that approximately 9 per cent of the gasoline consumed in the United States was wasted because of carelessness in its handling. A recent investigation of exhaust gases undertaken by the Bureau of Mines in connection with the Hudson River Vehicular Tunnel brought forth the significant fact that the combustible gas in the average automobile exhaust contains nearly 30 per cent of the heat of the original gasoline.[1] The great majority of passenger cars and trucks are operated on rich mixtures suitable for maximum power but very wasteful from the standpoint of gasoline economy. Careful carburetor adjustment alone would result in a saving in the country's annual gasoline consumption of upwards of 15 per cent, or 600 million gallons.

To the loss arising from careless operation must be added the greater one resulting from the low fuel economy attained by the average automobile engine. In the words of a leading automotive engineer: "The ordinary engine running around the streets of New York has a thermal efficiency of from 5 to 10 per cent. . . . I think that in five or ten years from now it will be common practice to secure in the neighborhood of 35 or 40 per cent thermal efficiency."[2] This conclusion, which is concurred in by many automotive engineers, indicates that a mileage of from 30 to 50 miles a gallon should be the ideal toward which both the public and the engine designer should look.

In addition to the added mileage, and, in consequence, the greater service that may be won from gasoline, it is also possible to adapt the automotive engine and equipment to the use of less volatile fuel, which will permit the enlargement of the motor fuel supply on the part of the refiner. The requirements of automotive transportation are growing so rapidly that a supply of motor-fuel can be assured for future years only by giving the utmost attention, not only to economy of operation, but also to the more difficult problem of modifying the engine, the character of the fuel, or both, so as to permit

[1] Fieldner, Straub, and Jones, Automobile Exhaust Gases and Vehicular-tunnel Ventilation, Jour. Soc. Aut. Eng., April, 1921, pp. 295–305.

[2] C. F. Kettering, More Efficient Utilization of Fuel, Society of Automotive Engineers, New York, February 6, 1919.

the maximum enlargement in the fuel supply. This issue was first brought to the concerted attention of the automotive industry and the oil industry by the Oil Division of the Fuel Administration in 1919, and since that time there has been progress toward cooperation between the producers of motor-fuel and the manufacturers of motors. The problem of coordinating engine and fuel is thought by many engineers to represent one of the most important issues now occupying the field of automotive transportation. The automotive engine in current use to-day is out of adjustment with the fuel supply and while marked adaptations upon the part of the engine are coming into evidence, the need is for a closer parallelism between the development of engine and fuel than has yet been attained.

Fuel oil is not only the cheapest of the main petroleum products, but it is also the one used in greatest bulk. Because of low cost and the rapid expansion in its consumption, it is for the most part very inefficiently utilized. The Bureau of Mines, in a Handbook by James M. Wadsworth entitled "Efficiency in the Use of Oil Fuel," issued in October, 1918, estimated that out of 160 million barrels of fuel oil burned in the United States in 1917, at least 40 million barrels or one-fourth of the total "might have been saved by more intelligent operation of plant and proper firing." There is little reason to believe that the efficiency of utilization has increased materially since this appraisal was made, and if oil is to be employed for fuel purposes, it should be used efficiently within this range of application.

In addition to the losses occurring in the actual use of fuel oil, there is an even greater economic loss involved in the fact that over two-thirds of the fuel oil consumed is burned under boilers for steam raising, a method of utilization which extracts a minimum of value from the product, but which is nevertheless profitable to the consumer so long as the price of fuel oil is low. This sort of utilization is not generally regarded as a loss, but the fact remains that a product capable of highly specialized applications is now devoted to the crudest of uses. With the development and widespread use of the Diesel and semi-Diesel type of internal combustion engine in the place of the oil-fired steam engine, the service gained from fuel oil may be doubled or trebled.

The outstanding feature of the fuel-oil situation of late is the rapid manner in which the requirements of transportation—automotive and marine—are encroaching upon the supply and competing with the uses which have thus far exclusively occupied the field. The rapid conversion of the navies and merchant marines of the world to an oil-fired basis, and the growth of gasoline requirements in

excess of the production of natural gasoline, are forcing a diversion of fuel oil from its industrial rôle to the rank of marine and motor fuel. With such rapidity has this diversion come about that accustomed channels of flow have suffered reduction and certain industries, such as the gas industry, have met with difficulty in obtaining their accustomed quotas. The elevation of fuel oil, and its light variety, gas oil, to higher economic levels, however, is a matter to be encouraged. Although commercially a single product at the present time, fuel oil is fundamentally a mixture of wax, asphalt, lubricating oil and motor-fuel. Just as it is now an economic perversion to burn crude petroleum in its raw condition, so it will soon become uneconomic to utilize fuel oil in its present composite form. It is only a matter of time when fuel oil will be refined into its components and thus utilized, but that time should be hastened by appreciation of the true values contained in this product and concerted efforts toward winning these values therefrom.

Of all the petroleum products, lubricants are fundamentally the most essential, for they support modern industrialism and their use cannot be dispensed with. In addition to the fact that millions of barrels of potential lubricating oils are burned annually in the United States in the form of fuel oil, the application of lubricating oils is in many instances far from scientific. In many installations it has been estimated that the needless losses arising from imperfect or faulty lubrication run from 10 to 50 per cent of the power consumed. If we visualize for a moment the vast quantities of coal and hydroelectric energy brought into service in the United States, and bear in mind that a large part is devoted to the overcoming of friction, we gain an adequate idea of the importance of lubricants as conservers of energy.

A lubricating problem of no small importance has developed of recent years as a result of the change in the character of motor-fuel induced by the mounting demands for this product. Because of the lessened volatility of fuel on the one hand, and the slow adaptation of the engine to this circumstance on the other, the life of lubricants in the automotive engine has been lessened through crank-case dilution. This matter is an example of a faulty development which could have been prevented in advance more easily than it may be corrected in the present.

The Natural-gas Analogy.—It is desirable to review the natural-gas situation in the United States since this product illustrates a resource closely associated with petroleum, which has been brought to the verge of exhaustion by rapid and hasty methods of exploitation and whose future would seem to be largely dependent upon the

extent to which constructive and enlightened conservation measures are brought to bear upon the prolongation of its life.

The production of natural gas reached its peak in 1917 with a marketed output of nearly 800 billion cubic feet, and since that time the production has been rapidly declining, with an estimated output in 1920 of less than 650 billion cubic feet. It is a serious matter when the production of an essential commodity serving directly over one-tenth of our population has entered upon a waning course.

In 1917–1918 the Oil Division of the Fuel Administration was faced with the necessity of dealing with the critical natural-gas conditions that were already displaying serious results. On the basis of extensive engineering data it was estimated that the common methods of producing, transporting, and using natural gas have resulted in losing more gas than has ever been brought into useful service. A report made by S. S. Wyer to the Fuel Administration indicated that the loss of natural gas to-day is greater than the quantity of gas actually utilized. Man, with all his skill, has never been able to make a commercial gas equal in quality to the natural gas now so lavishly and carelessly used. Natural gas has previously been so abundant in this country, and so little value has been placed upon its use, that the product has been carelessly and shamefully misused. Wyer, whose work on natural-gas conservation, both in the Fuel Administration and subsequently, turned so much light on what may be accomplished by effective conservation measures, has recently stated: ". . . the rate of decline of the (natural-gas) industry's field resources has been so rapid, and the provision for taking care of that depletion has been so inadequate, that, based on personal investigation of over one-half of the natural-gas industry in the United States, I am sure that at last three-fourths of the natural gas companies in the United States will be insolvent inside of three years if . . . the practice of selling natural gas at a figure so low as not to place any incentive on saving the gas, but actually putting a premium on waste, because the gas is cheaper than any efficient appliance that can be purchased or used to save it" is not corrected.

It would carry the discussion too far into detail to describe fully the various losses that take place from the well to the consumer under present conditions. The over-drilling of gas pools, the losses in transmission due to leaks arising from electrolysis and other causes, the dominant application of this choice fuel to low industrial uses, the wastefulness of the majority of appliances used in burning natural gas, the use of this fuel in the manufacture of carbon black in unsuitable localities, are all well known. Apart from the under-

ground losses and the needless employment of capital and labor in surplus drilling, the average losses for all natural-gas companies in the United States between the well and the consumer's meter are estimated, on good authority, to be from 30 to 35 per cent of the gas produced.[1] Then, of the portion passing the consumer's meter, 80 per cent performs no useful service owing to inadequate appliances and improper application.

The measures rapidly being adopted looking to fuller and more efficient utilization of our dwindling supplies of natural gas afford an interesting object lesson on the change that comes when the output of an essential commodity runs definitely short of requirements.

The Situation in Perspective.—The losses taking place in the exploitation of petroleum have called down many critical statements as to their magnitude and the ultimate consequences. For the sake of the perspective afforded by the outside view these appraisals may not be without value.

Sidney Brooks, an English journalist, writing in "The Nineteenth Century," reflects the consensus of opinion abroad when he remarks:

> America, as one would expect, has been the classic home of all that is hasty, negligent, and well-nigh criminal in the misuse of oil as of every other form of natural wealth; and America in consequence finds herself to-day consuming more oil than she produces and faced with the prospect that her deposits may in thirty years be nearing exhaustion. Huge oil-tank and gasometer as she is, it is doubtful whether in the past sixty years America has not lost for all time more petroleum and more natural gas than she has won from the earth.

The Director of the U. S. Bureau of Mines[2] has said:

> What effort have we made to conserve this supply and to utilize it to its greatest advantage? We have made little effort until very recently to do these things. We have been wasteful, careless, and recklessly ignorant. We have abandoned oil-fields while a large part of the oil was still in the ground. We have allowed tremendous quantities of gas to waste in the air. We have let water into the oil sands, ruining areas that should have produced hundreds of thousands of barrels of oil. We lacked the knowledge to properly produce one needed product without overproducing products for which we have little need. We have used the most valuable parts of the oil for purposes to which the cheapest should have been devoted. For many years the gasoline fractions were practically a waste product during our quest for kerosene; with the development of the internal-

[1] Address of S. S. Wyer, Conference on Natural Gas Conservation, Washington, January 15, 1920.

[2] Yearbook of the U. S. Bureau of Mines, 1916, Washington, 1917, p. 117.

combustion engine the kerosene is now almost a waste product in our strenuous efforts to increase the yield of lighter distillates.

The Smithsonian Institution[1] reports:

> Under present practice, from 90 to 30 per cent of the oil is left underground. Then, of the quantity produced, an appreciable percentage is lost by fire, and a significant portion dissipated by seepage and evaporation due to inadequate storage facilities. On the average, therefore, it is safe to say that less than 25 per cent of the petroleum underground reaches the pipe-line. If we subtract from this proportion the losses involved in improper and wasteful methods of utilization, the recovery factor becomes perhaps as low as 10 per cent. . . .

In 1919 an English writer[2] attracted widespread attention with these startling words:

> America has recklessly and in sixty years run through a legacy, that, properly conserved, should have lasted her for at least a century and a half. . . . Just when Americans have become accustomed to use twenty times as much oil per head as is used in Great Britain; just when invention has indefinitely expanded the need for oil in industry; just when it has grown to be as common and as true a saying that "oil is King" as it was twenty years ago that steel was king; just when the point has been reached where oil controls money instead of money controlling oil—the United States finds her chief source of domestic supply beginning to dry up and a time approaching when instead of ruling the oil market of the world she will have to compete with other countries for her share of the crude product. . . .
>
> America is running through her stores of domestic oil and is obliged to look abroad for future reserves. . . .

Efficiency a Necessity.—For the oil industry there is a single cloud upon the horizon—raw material. A problem is coming to be recognized which, in the earlier days of the industry, was too far removed to appeal to the practical man. It has been reiterated until everyone is tired of hearing it that the demand for oil is exceeding the supply. This country is growing with startling rapidity into dependence upon foreign sources of petroleum supply. What does that simple fact mean? It means that we must pay growing attention to all methods, engineering and economic, that will conduce to the fuller utilization of the raw material that we have. How much we have, no one can say precisely; that the supply is unlimited, no one would now have the audacity to assert; that the supply is inad-

[1] Petroleum: A Resource Interpretation.

[2] E. Mackay Edgar in Sperlin's Journal, September, 1919.

equate to our needs is a fact requiring no further proof. We must extract a greater percentage from our underground reservoirs; we must more carefully guard the oil extracted from evaporation, contamination, and fire; we must refine that oil more carefully, turning more of it into products of high economic rank; we must have regard for the appliances utilizing the products of that oil, to the end that the full service may be drawn from the commodities that are turned over to consumption. More than this, we must more carefully adapt the rate at which we produce and refine to the highest requirements of the market; we must coordinate and integrate our activities that the raw material which lies at the foundation of the whole activity may be increased in productive capacity. We have passed the time when we can continue to grow through increments of volume alone; we must now take advantage of the multiplying power gained through the balanced employment of the creative agencies of production. We must make what we have go further and do more; we must become efficient, not by the measure of others less efficient, but by the measure of those in the lead. The oil industry has assumed an obligation for supplying the vital needs of modern civilization; its best efforts will be required to live up to that responsibility.

CHAPTER XXIX

THE FUNCTION OF STATISTICS IN THE PETROLEUM INDUSTRY[1]

Standing of Statistics now Inadequate.—Mathematics has been defined as the science of rigorous thinking. Statistics may be defined as a branch of mathematics which facilitates the application of rigorous thinking to the problems of action. In the realm of business and industry, the science of statistics affords, or should afford, the means for measuring the use of energy, materials, and capital to the end that they may be most productively employed. As a practical tool, statistics has been inadequately utilized and the field stands in need of suitable recognition and proper rank amongst the agencies of production.

The Threefold Character of Statistics.—The science of statistics, as thus far developed, is divisible into three fundamental, though somewhat overlapping, divisions, which may be termed (1) accounting, or record statistics, (2) engineering, or operating statistics, and (3) planning, or economic statistics. Accounting statistics has been highly developed and may be regarded as in its maturity; engineering statistics has been accorded moderate application and is in its youth; economic statistics has only recently come into action and its practical application is still in its infancy. In business and industry, the utilization of statistics has suffered from an unbalanced growth, because of the comparative neglect of two important functions.

Accounting Statistics.—Every business organization as a matter of course maintains accounts, or accounting statistics, which represent a record of what has happened for purposes of meeting financial and legal requirements. Such a record constitutes a mathematical account of all transactions in goods and dollars, expressed in a form specified by the requirements of law and corporate finance. Accounting statistics are highly developed and rigorously standardized in business practice. Their character is familiar to all. They culminate in the conventional balance sheet, and they form the basis of taxation, loans, credit extensions, and other financial operations of business enterprise. Accounting statistics are universally employed

[1] Adapted from an address by the author before the American Petroleum Institute.

because of their obvious necessity. The preparation of accounting statistics, however, is a static function. This activity is primarily concerned with the measurement of tangible assets, but pays little attention to how those assets are being used.

Engineering Statistics.—Because of the necessary establishment of accounting as an integral part of business organization, only secondary consideration is customarily given to the provision of data in a form adapted to improving the operating efficiency of the undertaking. For purposes of management, accounting data are, in consequence, usually used, although such material is designed for a different purpose and is not suited to this end. The widespread employment of accounting statistics for managerial purposes is a source of weakness in many organizations, leading to loss and inefficiency, and sometimes to failure.

Accounting statistics, therefore, need to be supplemented by engineering, or operating, statistics which will afford a measure of actual performance and suggest means for improving that performance; in short, for increasing the productivity of the enterprise. The function of engineering statistics is to provide a picture of what is happening in such a form that:

(*a*) The unproductive portion of the equipment may be recognized.
(*b*) The efficiency of the productive portion of the equipment may be measured.
(*c*) The causes of unproductivity and inefficiency may be made apparent to the end that they may be corrected.

Engineering statistics, moreover, in addition to providing a guide for management should be made to furnish superintendents, foremen, and workmen records of their own individual operations in order to arouse their creative and emulative instincts and increase their productivity. It has been amply demonstrated by a number of industrial engineers that by keeping individual records of production and systematically attempting to remove obstacles which prevent complete accomplishment, a notable degree of cooperation is attained and unsuspected possibilities developed in the working staff.

Fig. 1, on page 2, shows the economic structure of the oil industry and suggests the headings which engineering statistics should cover.

H. L. Gantt has strikingly described the difference between engineering statistics and accounting statistics as comparable to the difference between a moving picture and a photograph.

Economic Statistics.—In the early growth of business and industrial activities, with bountiful resources and expanding markets, economic statistics have systematically been used even in less degree than engineering statistics, although they have always been taken into account in a qualitative and imperfect manner. Economic statistics are needed for planning accurately and effectively, for keeping efforts on the right track, and as a support to engineering statistics in operating.

Success in management depends in large degree upon the extent to which accumulated experience can be rendered available for use, and upon the exactitude with which conditions ahead can be appraised. The primary function of economic statistics is to gather the experience of the organization, of the industry of which the organization is a part, and of business and industry in general, and to render this composite experience available for use in the problems of management and planning. A further purpose of economic statistics is to provide a comparison of actual performance with outside standards of accomplishment, as well as to measure the results of any given course of action with a view to determining its efficacy and justifying its continuance or termination. For the sources of economic statistics, the whole business and industrial field must be scanned—Government activities, technical and trade associations, trade publications, research bureaus, and the vast range of financial and economic literature.

Under the complex conditions of modern industrial activity, efficiency in management is predicated more and more upon a coordinated and balanced development of accounting, engineering and economic statistics; and the development and furtherance of both engineering and economic statistics are matters of urgent importance, involving investigation, research, and engineering practice of a rigorous and exacting character. The field of engineering and economic statistics is underdeveloped, and much able effort should go toward perfecting and extending its applicability and insuring its adequate integration with the more accustomed means of managerial control.

Fig. 151 is a chart of the economic structure of business and industrial activity, and suggests the topics to be covered by economic statistics in the field of general business and industrial conditions.

Statistical Technique.—The technique whereby statistics, in their broad meaning, may be brought to adequacy as a working tool is by no means perfected, and if statistics are to meet the responsibility placed upon them by modern industrial requirements, considerable attention must be accorded the means for gathering, analyzing, inter-

preting and presenting the facts upon which the success of any enterprise is coming more and more to depend. There is need for mutual understanding and constructive cooperation between the various agencies concerned with this activity, to the end that there may be a

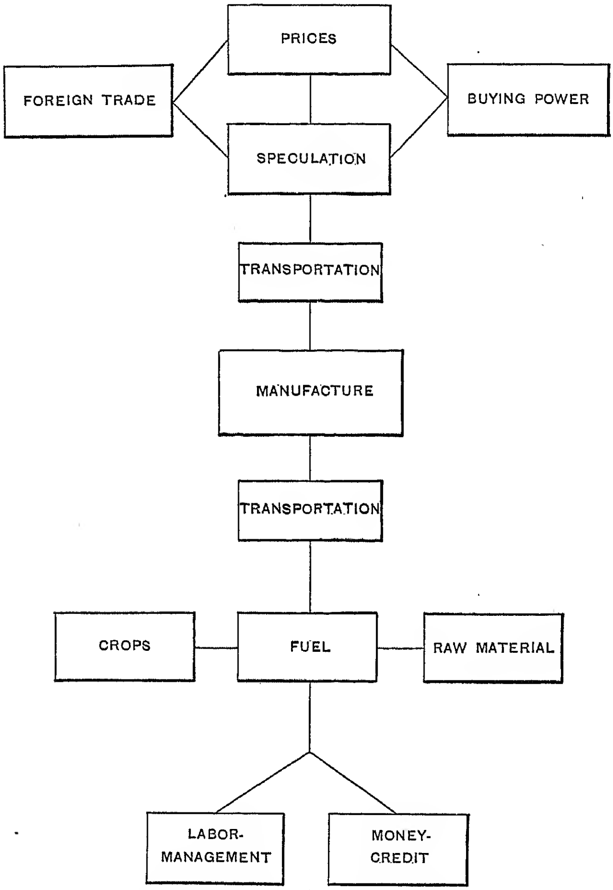


Fig. 151.—Chart of the industrial structure showing the sub-divisions of the field for economic statistics.

free interchange of ideas and methods, and that an effective technique may be built up and established.

Gathering of Statistics.—Accounting and engineering statistics are inherently a responsibility of the industrial unit itself, but economic statistics must be drawn not only from the operating organization, but quite extensively from external sources, especially Government activities, industrial and trade associations, the trade press

and a wide range of financial and economic sources. In respect to economic statistics, the oil industry has available a more complete and accurate record of the flow of its raw materials and manufactured products than most other industries enjoy. The economic statistics of crude petroleum furnished monthly by the U. S. Geological Survey and the economic statistics of refined products supplied each month by the U. S. Bureau of Mines are valuable material. A drawback to these figures, however, is the delay intervening before they are made available to the industry, and every effort should be bent toward decreasing this interval in order that their usefulness may be enhanced. The American Petroleum Institute is making creditable efforts in this direction. In the gathering of statistics, the trade press has somewhat confined its efforts to well data, field production and price quotations. In all three respects there is some room for improvement in accuracy and continuity.

Analyzing Statistics.—In the analysis of statistics no standardized technique is available. A great gain in convenience and effectiveness may be made by devising and using appropriate analysis schedules which will automatically make the primary analysis. The use of index numbers has been largely neglected and this convenient device may be effectively employed in many directions in the oil industry. Various other mathematical devices and expedients for weighting, averaging, combining, etc., may be employed to advantage in specific instances. The technique in these various directions suggested by the interesting work now being conducted by the Harvard University Committee on Economic Research and published in the Monthly Review of Economic Statistics is of value in this connection.

For purposes of statistical analysis, graphic methods are of outstanding importance. Natural-scale graphs are suitable for size comparisons, whereas the use of semi-logarithmic charts gives remarkable results where trend comparisons are important. The use of graphic methods for purposes of analysis offers a fertile field for further research and development.

Interpretation of Statistics.—After statistics are gathered and analyzed, the most difficult task still remains—their interpretation. The proper interpretation of statistical results, it goes without saying, requires the highest type of ability. To draw therefrom full significance and accurate meaning demands not only acquaintanceship with statistical technique, but a knowledge of engineering, economics, and technology in the field to which the figures pertain. Accurate interpretations, moreover, demand the research point of view, together with practical contact with the problems dealt with. Effective work in the gathering and analysis of figures is of no avail

if they are not correctly interpreted and if their full meaning is not deduced.

Presentation of Statistics.—The final step in statistical work is the presentation of the results. Nothing of practical value has been accomplished until the results are brought into action. There has been failure in much statistical work to pay proper attention to this phase of the activity. The presentation of statistics is not merely a science—it is an art as well.

In the exposition of statistical results, it is notable that rather simple and obvious expedients for gaining clarity and effectiveness are usually overlooked. For example, statistical tables gain in simplicity and in the readiness with which they may be grasped, if the figures are expressed in large units and fractions thereof instead of in smaller units of the barrel and gallon. For the presentation of statistics, the use of graphical devices is highly advantageous and great advances are here possible over the common practices in this respect. Graphics serve not only to impress the facts upon the mind, but to show their interrelationships, thus affording ready comprehension. Numerical statistics are like the description of a picture; graphically expressed statistics are the picture itself. Graphics afford not only ease of comprehension, but in addition provide that most important essential—perspective. Space prevents extended discussion of the technique of graphic presentation, but much can be gained from "Graphic Methods for Presenting Facts," by Brinton and "How to Make and Use Graphic Charts," by Haskell, while the pages of the present book may prove suggestive. Effective results may frequently be attained by combining tabular and graphic presentations.

Graphic charts are applicable not only to purposes of management, but are also especially valuable for the operating staff and the individual workman. The employee should also be the beneficiary of visual methods. To visualize data and information is to add to human intelligence and effectiveness.

Research.—Statistical research, or, using the preferable term, economic research is growing in importance as a method for investigating operating and economic conditions for purposes of contributing to productivity and accuracy of planning. Research—the making of careful measurements and the drawing of appropriate deductions therefrom—is the vital part of statistical work, and without the scientific point of view the handling of statistics becomes a mechanical and routine matter, and the results are inadequate and likely to be misleading.

The importance of statistical, or economic, research was recog-

nized earlier in finance than in industry, as evidenced by strong statistical and research bureaus in banking and investment establishments. It goes without saying that the whole field of insurance is grounded upon the results of research in vital statistics—to such a degree, indeed, that this business has itself the distinction of being virtually an exact science. It is to be noted that statistical research has been extensively developed by advertising agencies and trade publications. Now the up-to-date advertiser makes extensive and close use of research methods in appraising the markets which the advertising is designed to reach.

During the war, statistical (economic) research became extensively necessary as the basis for the coordination of the country's production and the allocation of its products. At the present time, economic research is developing rapidly in the larger and more complicated industries, especially the packing industry, the steel industry, the rubber industry, the automotive industry and the oil industry, where this activity is found under various names such as "statistical research," "commercial research," "trade promotion and research," "market control," "engineering statistics," "economic research," and the like.

Research in the Petroleum Industry.—The opportunity for statistical, or economic, research in the oil industry is especially outstanding by virtue of the rapid changes that are taking place in this activity and the important and extensive range of service rendered by the products of petroleum. Because of the rapidity with which the raw material base is changing in geographical position, chemical character, and volume, and because of the acceleration of demand over supply as working through a multiple production type of fabrication, the economic balance between the various petroleum products is altering with notable rapidity. The detection and measurement of these conditions, and the coordination of the tendencies with market requirements on the one hand, and operating conditions on the other, afford wide scope for careful inquiry and effective results. Among the subjects that may be covered in such work are price studies, appraisals of supply and demand, measurement of marketing territory and requirements, analyses of consuming activities such as the automotive industry, statistical measurements of the effects of changing technology, and so on, not to mention more specific analyses making use of both accounting and engineering statistics in connection with operating conditions.

Conclusion.—In short, adequate statistics represent the means for attaining engineering control of operations, to the gain of increased productivity and more effective planning. The development and

balanced employment of accounting, engineering and economic statistics, directed from the research point of view, are essential to this end. As a concrete example of operating and planning on the basis of the findings of statistics, there may be mentioned the instance of the railroad executive who appreciating that earnings are made by the ton mile and expenses incurred by the train mile, determined every action by the extent to which it contributed to the increase of ton miles and to the decrease of train miles.

INDEX